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THE

PURIFICATION OF SEWAGE AND WATER.

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BOARD OF ESTIMATE AND APPORTIONMENT
Office of the Chief Engineer
17 BATTERY PLACE.

THE

PURIFICATION

OF

SEWAGE AND WATER.

BY

W. J. DIBDIN, F.I.C., F.C.S.,

ETC.,

Formerly Chemist and Superintending Gas Examiner to the London County Council and the late Metropolitan Board of Works, from 1882—1897.

THIRD EDITION

REVISED AND ENLARGED.

London:

THE SANITARY PUBLISHING COMPANY, LIMITED,

5, FETTER LANE, E.C.

1903

BOARD OF ESTIMATE AND APPORTIONMENT
Office of the Chief Engineer
38

LONDON:
PRINTED BY C. F. ROWORTH, GREAT NEW STREET, E.C.

PREFACE.

When the first chapters of the present work were published in 1896 the bacterial principle of sewage treatment was in its infancy, and many adverse opinions were strongly expressed as to its merits. Still more opposed were the views of many when I published my first report on the experiments on the bacterial treatment of the London sewage at Barking Creek in 1892; whilst, going still further back, the reference to the question in my paper read before the Institute of Civil Engineers in 1887, some ten months before the Massachusetts experiments were commenced, was met with pronounced scepticism. The subject, however, has entered a different phase at the present time. A Royal Commission has been sitting for about four years, and has published three Reports, with voluminous appendices. Large numbers of patents have been taken out for various modifications in detail working of the essential principles originally laid down for the utilisation of the life processes of bacteria for the destruction of sewage matters, and many text-books have been written.

It was originally clearly defined that the action of the bacteria was necessary to effect purification of

sewage matters, whether this took place in a river, on land, or in artificially constructed beds. The advocates for land treatment were at first puzzled at this, and the sellers of "oxidising" agents stoutly denied it; but now the truth of the statement is admitted, and, further, it is agreed that artificial bacterial treatment is more under control than is that on land in a large number of instances. The results of the extensive experiments carried out by my successor, Dr. Clowes, at Barking Creek; and those at Manchester; Leeds; Leicester, and elsewhere, the official reports of which form a library in themselves, have placed the subject in a totally different aspect to its former one of a tentative proposition, and the present and ultimate success of the principle is assured.

Much confusion seems to have arisen with regard to definitions. For instance, in the report of the bacteriologists to the Royal Commission comparisons are made between "Dibdin" and "Cameron" beds. Evidently the writer of the report was unaware that these are synonymous.

The "Dibdin" beds were first used in connection with the experiments at Barking Creek and Sutton, and their use is not subject to patent rights or other charge. As stated elsewhere by Mr. Cameron, when he commenced his experiments with septic tanks at Exeter he used beds similarly worked, taking that at Barking Creek for his

example, which he was perfectly entitled to do. In order to make the action of the filters automatic he devised the alternating gear for distributing the effluent on the filter beds and giving the necessary time of contact. Possibly what is meant is that on one of the "Barking Creek," or "fine bacteria beds," or "contact beds," as they are indifferently called, an effluent from a septic tank was treated, and on another similar bed an effluent from a coarse-grained bacteria bed was turned, so as to ascertain what effect, if any, the different preliminary treatment of the sewage brought about.

With regard to the method of working these beds it is satisfactory to find that the time allowed for resting when filled with sewage, viz., two hours, originally worked out at Barking Creek and Sutton, has been invariably found to be a fair average working time with all sorts and kinds of sewage.

Much error has also arisen as to the method proposed and successfully adopted at Sutton, Surrey, for the disposal of the crude fine matters in suspension in ordinary domestic sewage. It was found that the fine breeze beds at Barking Creek, and later those tried at Sutton, disposed effectually of some seven grains of finely divided suspended matters per gallon in the effluent. Judging from this result, I argued that if the coarser matters were kept off a bed the finer organic particles might be similarly treated, and accordingly suggested that a bacteria bed should

be constructed similar in character to the fine beds, but filled with a coarser grained material so as to ensure the admission into the body of the bed of the fine particles of suspended matters left in the sewage after a process of fine screening. This was accordingly tried, and worked successfully with the sewage of Sutton, which is a purely residential town. The first bed tried worked successfully for five years, when it was put out of use in consequence of the necessary re-arrangement of the works for the permanent adoption of the new system, in connection with which a detritus tank was employed to avoid the necessity for screening.

I hoped that this original coarse bed would have been allowed to stand longer, in order to test its capability to completely restore it to its full water capacity, as was found to be the case with the first one-acre bed at Barking Creek, which had been completely sludged up by continuous working (see p. 58). Unfortunately press of work rendered it impossible for me to continue to serve as a member of the Sutton District Council, and in my absence the bed was destroyed in connection with the more convenient re-arrangement of the works.

The system of allowing the sewage to undergo preliminary decomposition in a tank, which was introduced by Cameron at Exeter, and Scott-Moncrieff at Ashtead, effects the separation of the mineral matters and the grosser solids, as was the case in

the precipitation tanks at Barking Creek, and enables the finer particles in suspension, as well as the dissolved solids, to be treated as on the Barking Bed, or on various forms of trickling filters. It will be seen later, that in the opinion of some, simple sedimentation without excessive anaërobic action is preferable.

In the first edition suggestions were made for the guidance of those who desired to try the bacterial bed system of treating crude sewage after it had been properly screened, and the grit allowed to deposit. The principles then laid down have been largely adopted with considerable success, and form the foundation of the majority of sewage schemes promoted during the past few years. The employment of old precipitation tanks as a preliminary to contact beds is working on the lines of the original Barking experiments, and they have been found to work efficiently, whilst there is no question of expensive patent rights. If it is desired to see what can be done by the simplest means, with a low capital and working expenditure, a visit to the Worcester Park Works in Surrey will be well repaid. When I took these works in hand five years ago, two actions for injunctions were threatened, as they were causing an intolerable nuisance. An expenditure of about 500*l.* put them in order for treating nearly 100,000 gallons of sewage daily, and produced, and still produces, one of the finest effluents I have seen. The means are so simple that they

form one of the most useful object lessons possible. I was, however, given a perfectly free hand in the matter, untrammelled with the preconceived ideas of others, nor with official regulations, and therefore able to make full use of the natural advantages of a *stiff clay* field.

The laborious and invaluable work of Lord Iddesleigh's Commission has brought into focus a mass of information as to the actual results attained by means of the various modifications in use for applying the principle of utilising the life processes of bacteria for the destruction of refuse matter. The evidence given before the Commission extends over 544 of the closely printed pages of Vol. II. of the Interim Report, and embodies the experience of all those whose names have been prominently before the public in connection with the subject of sewage disposal. After careful perusal of this evidence, which is too extensive to be summarised without a very complete analysis of the various heads, a few points crystallise themselves out, as it were, before one's mind. For instance:—(1) It is clear that whilst efficient land treatment is held to yield excellent results, there is strong doubt as to the wisdom of employing it solely under all circumstances. (2) That the bacterial principle is the fundamental one underlying land treatment, as well as the most efficient artificial method. (3) That bacteria or contact beds will efficiently purify sewage either with or without the preliminary aid of the anaërobic action in

either a covered or uncovered tank. (4) That the use of such tanks greatly assists the life of the beds by preventing their becoming choked by the accumulation of mineral and indigestible fibrous matters. (5) That the anaërobic process may be carried too far so as to interfere with the subsequent aërobic action on the beds or land. See Mr. E. G. Mawbey's evidence (8244, 8253, &c.): "What I want to bring out is this, that when we put this septic effluent through a bed and then on to the land it was no better than when we put it straight from the detritus tanks on to the land. In our experiments for clarification before putting the sewage on to the land we were no better off by using a sèptic tank in addition to the detritus tank before we put it through the first contact bed." "In fact, it was at once, in a word, the most successful of all the clarifying systems to send it through a closed detritus tank, and then on to a contact bed, and then on to the land. Now what happened was, we never had the slightest nuisance nor any fouling of the grass, excepting for a distance of about twelve yards from the top feeding grip when we treated sewage which had only passed through the detritus tank and the first contact bed." The experience of Mr. Fowler (8415, &c.) at Manchester appeared to agree with this view, but not quite so definitely. "Very probably you can allow the septic action to go too far, that the effluent becomes foul, and it does not subsequently oxidise as readily." (8417) "You have told us that your results were obtained from a

flow which would fill the tank in twelve hours. Is not that so?—Yes, that is so." (6) There is a clear consensus of opinion that results may be obtained from double contact beds equally good to that obtainable from land, and that the beds are more under control. (7) That whilst no process yields a sterile effluent, the most suitable method of approaching that end in practice is the final filtration of the effluent through sand filters as used by water companies.

In Chapter X. of the first edition of the present work I formulated a series of "suggestions to be considered in the light of a 'general idea' which should 'be modified to suit local conditions.'" These were shortly as follows:—"As a preliminary it will be advisable to remove as many of the particles as possible by mechanical separation, by passing the sewage through a screen having as fine a mesh as possible—the best and most economical method yet remains to be worked out—the more perfectly this is accomplished the nearer perfection we shall attain in our subsequent work."

The experience of Mr. Mawbey and others clearly confirms the view that this "mechanical separation" can best be carried out in a detritus tank without undue septic action.

On page 130 I recommended the use of very fine breeze or sand as used by the water companies, when very superior effluents were required. I further pointed out on page 133 that it might be desirable to

resift the whole of the filtering material in time, and that the expense would not be insuperable. Mr. Strachan in his evidence (Q. 7721) points out that as compared with the cost of chemical treatment, it would be profitable even to pay 10*s.* per cubic yard to renew the bacteria beds at the end of three-and-a-half years.

With regard to this point I am indebted to Mr. R. F. Grantham, M.Inst.C.E., for the following particulars of the cost of labour for emptying and refilling the bacteria beds at Alton, Hants, where about 33 per cent. of the dry weather flow is brewery refuse. The works were started in 1899, and after three years' work the filling material has been changed. The tanks were originally intended for chemical precipitation, but were adapted to bacterial treatment. The labour cost 1*s.* 2*d.* per yard, or, say, 5*d.* per yard per annum. The five beds, equal 830 yards, have treated 160,000 gallons daily plus subsoil leakage. This quantity is equal to over 200,000 gallons per yard, so that 5 yards will have treated 1,000,000 gallons, the cost of which for renewing the material in the beds from a reserve supply would be 5*s.* 10*d.*

Now I do not want to be misunderstood. I quite acknowledge the value of the work done in a detritus or a septic tank, and the prolonged life afforded to the beds by their use, but I cannot overlook the fact that either of these methods leads to the collection of

quantities of offensive sewage sludge which has to be disposed of sooner or later. The use of the coarse bacteria bed does, as a simple matter of fact, do away completely with the sludge nuisance, but it involves an expense from time to time in taking out the material from the beds, throwing it on a spoil bank for say twelve months to completely recover, and the use of a stand-by quantity of filling material to fill up the beds as may be required. By this method there is absolutely no sludge and no offensive odours.

However, it is clear that the consensus of opinion at the present time is in favour of the use of detritus or septic tanks, followed by either:—(a) single contact bacteria beds and land, (b) double contact bacteria beds where suitable land is unavailable, (c) trickling filtration, or (d), when the best possible effluent obtainable is required, double contact beds, and either very suitable land or fine sand beds as used by water companies.

Much attention has been devoted to the sprinkling of sewage over bacteria beds in which the effluent has a freeway to escape without the use of valves, after the method introduced by the late Col. Ducat. The latest outcome of this work is described in the evidence of Col. Harding as the "Leeds filter," which is constructed of brick walls 10 ft. high and is 12 ft. square. It has at the bottom semicircular perforated pipes, 9 in. diameter, but air can only reach the bed through the 6 in. opening of the outlet valve which

remains wide open. At a point 3 ft. above the ground a + of perforated pipes is laid, and another 3 ft. higher. Communicating with these, half brick openings are maintained in the walls, with half bricks loosely put in, so that they can be taken out to obtain samples if necessary. Although it was considered that the bottom of a trickling filter should be complete, they were anxious to try a filter without side aëration at all, for experimental purposes, and to be able to regulate the bottom aëration.

The sewage was distributed over the surface by means of a sprinkler, and the quantity of sewage treated was at first equal to a rate of 200 gallons per square yard per twenty-four hours, and then increased to 400 gallons per square yard. The sewage passed through the filter in about three minutes, and gave a purification of 86% of albuminoid ammonia, and 89% of oxygen absorbed, whilst the nitrates in the effluent equalled 0·434 grain of nitrogen per gallon.

When speaking of the results Col. Harding said (Q. 7396): "I think it is practicable to devise automatic screening to remove from the sewage the grosser suspended solids and fibres, which are but very slowly reduced in a filter. Given the satisfactory removal of these matters (which are readily combustible or otherwise dealt with, for they are not in the form of sludge), I think it is quite practicable to deal with Leeds sewage on trickling filters without antecedent septic treatment; and I think that possibly there will

on this system be a greater digestion of the suspended solids. Another advantage would appear to be the absence of nuisance in consequence of limiting the treatment to aërobic action. As fresh sewage does not stink, and as its treatment on our Leeds beds is marvellously rapid, only requiring a few minutes, I don't see how any nuisance can possibly arise; while with septic tanks, the septic effluent at least is offensive, and, as I found at Accrington, in summer weather is likely to cause a smell, while smell will possibly arise from the drying of the septic tank sludge." (Q. 7398.) "Then, briefly, you prefer trickling filtration to contact filtration, and you don't think that antecedent septic action is necessary for trickling filtration; indeed, that on the ground of probable nuisance arising, such septic action is objectionable?—That is my present opinion—with Leeds sewage."

It will be seen that the view as to the undesirability of the septic action previous to trickling filtration agrees with Mr. Mawbey's experience in regard to treatment on bacteria bed and land.

In reply to Q. 7461, Colonel Harding said:—"I think in the case of domestic sewage a septic tank is almost necessary for the purpose of breaking up the suspended solids into a finely divided condition."

In connection with the employment of open septic tanks, the odour arising from these may be prevented by the use of a layer of peat moss 6 inches thick,

supported on tarred sheep hurdles resting on any convenient supports. This was tried, on my suggestion, at the Carshalton Works, where it has been most successful in completely stopping the nuisance from the tanks.

The trend of the bacteriological evidence is in the direction of bacteriological standards for testing the purity of effluents. Unfortunately the extensive bacteriological examinations which have been made do not seem to have done more than throw a certain amount of light on the actual work going on in bacterial installations; they have not pointed out any distinctly new departure, but merely served to indicate the number and kind of various organisms present in sewage and effluents, and to show the potential danger present in all effluents from the presence of pathogenic organisms, a result leading to the suggestion that if possible some means should be adopted for the complete sterilization of all effluents before their final discharge from the outfall.

It must not be taken that these few abstracts are intended to represent more than some of the salient points which seem to fix themselves on one's mind as being the more material ones in a host of valuable suggestions of all sorts and kinds. What the ultimate decision of the Commission may be it is impossible to forecast with safety, but from the information available in their official reports and the cross-examination of witnesses it is clear that bacterial

systems have "come to stay," and that the desired result may be secured by either of several methods of applying that principle, and that the natural process of the survival of the fittest will gradually result in the establishment of certain methods applicable to different classes of sewage with certainty and success.

I desire to acknowledge the valuable help rendered by many in the preparation of the present Edition, particularly to Sir T. Bosdin Leech and the Rivers Committee of the Corporation of Manchester, for permission to insert the valuable Report by the experts, viz., Dr. Frankland, Mr. Baldwin Latham and Professor Perkin, and the summarised Report by Dr. Fowler and Mr. James P. Wilkinson, who have kindly corrected and brought it up to date. Also to Colonel Harding, Mr. T. Hewson and Mr. Harrison for the account of the carefully conducted experiments at Leeds which I have abstracted from the Reports prepared by them.

The continued researches on the bacterial treatment of the London sewage, carried out by Mr. E. Brooke Pike and Mr. Biggs under the direction of Dr. Clowes, with the co-operation of Dr. Houston, will be read with interest, and I have to tender my thanks to the London County Council for permission to embody them in the present work.

An important feature will be found in the account of the connection between the consumption of shell

fish contaminated by sewage and infectious disease, for which I am indebted to Dr. Arthur Newsholme, Medical Officer of Health of Brighton. The information on this important question is so admirably arranged in his Reports as to leave it unnecessary for me to make further comment other than to thank him for his kind permission to insert the necessary extracts.

W. J. DIBDIN.

2, Edinburgh Mansions,
Westminster,
June, 1903.

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clear and succinct manner. In due course the work will deal with the consideration of the character of foul matters in sewage and waters, their composition, and the processes involved in their ultimate destruction, either by combustion, which may be oxidation by the aid of fire, or by the action of organisms acting in the presence of air, accompanied or not by putrefaction which is brought about by the action of organisms acting in the absence of air; and the effect of various antiseptics resulting in the preservation of objectionable matters, for more or less prolonged periods. This will lead to a consideration of the different methods proposed from time to time for the purpose of effecting ultimate purification, such as precipitation by different chemical reagents, farming operations, and filtration.

Following this *résumé* of the general considerations, the experiments which have been made in England and America on the treatment of sewage matters and the results of the experimental operations on the filtration of sewage will be of interest.

No work of this kind can be complete without a discussion of the much-vexed question of the ventilation of sewers and the most suitable means of preventing offensive emanations. This subject is one which has given rise to considerable debate; but space will be occupied by a recital of only those features which are essential to the question.

The consideration of such a widespread subject requires a full description of the process in use for purifying the river Thames. When the question as to what process should be adopted for the purpose of effecting that great work was under consideration, no small discussion took place on the matter; and the scheme proposed by the author, which was ultimately adopted and is still in use at the present time, was submitted to a most searching criticism.

In the first edition an outline of a scheme for works for treating one million gallons of sewage per day was offered for consideration, and served to indicate the direction in which future improvements were anticipated. In making this suggestion, which was merely a systematised arrangement of known working conditions, the author did not wish to make dogmatic assertions, or in the slightest degree to indicate more than a direction of desirable procedure. The method then indicated has been followed with much success. Improvements in detail have been made, but in principle the system is now followed in the majority of instances, as without the Bacteria Beds, used either as "Contact Beds" or "Trickling Beds," few installations would be successful.

The question of the artificial purification of water for potable purposes affords matter for a chapter in which the history of the various methods which

do not agree. As I once remarked, in reply to such a suggestion, "The great stumbling-block in the way of a proper solution of the difficulty was the interested motives and unfounded statements of many who were absolutely unacquainted with the practical difficulties of the case. If the efforts made to tear aside the veil from these various mysterious processes were in any way successful, an enormous stride would have been made. Immediately sanitarians recognised the fact that the power of chemistry in this matter was limited, that sewage had to be got rid of at the cheapest rate, whether profitably or not, and that common sense was in many respects the best guide, a new era in the treatment of sewage would have arisen, and rapid progress might be anticipated."* Looking back on the experience of the past fifteen years, I can read these remarks and repeat them with ten-fold force. The antiseptics for sewage treatment have faded out of sight, and it has come to be recognised that the microbic action is the only one now worth further study, whether this be carried out in water, on land, or in artificial beds.

When I first proposed to treat the London sewage on biological principles the suggestion was met with much scepticism; it may, therefore, not be out of place to put on record the way in which the present scheme of treating the London sewage came to be worked out.

In my earlier years I was, like many others, a lover of aquaria, and spent much time in roaming over the delightful fields of Hampstead and Highgate in search of specimens. The study of these prepared me for the results of Dr. Sorby's microscopical examination of the river Thames in 1880—1882. From this it will be readily gathered that when, in the early summer of 1884, the Metropolitan Board of Works gave

* Inst. C. E., 1887.

the order to deodorise the whole of the London sewage, I was prepared to deal with the river in the light of a big aquarium, and looking upon my early experiences, and having Dr. Sorby's observations in my mind, I came to the conclusion that whatever chemistry could do, it must be subordinate to the biological considerations. In order, however, that in a matter of such vast importance I should not make a mistake, I obtained official sanction to consult Dr. Dupré, who heartily worked with me.

That he was in close agreement with me in these views will be seen from the following extracts from a report presented by him during that year to the Local Government Board, on "Changes in the Aëration of Water as Indicating the Nature of the Impurities therein":—

"If a perfectly pure water, fully aërated, were kept in a bottle in such manner that it could neither lose nor absorb oxygen, it would, no doubt, remain fully aërated for any length of time. If, however, the water contained any kind of impurity capable of combining with oxygen, the proportion of oxygen remaining in the water would after a time diminish. The amount of oxygen thus disappearing might, to a certain extent, be taken as a measure of the amount of matter present capable of combining with or consuming free oxygen. In this respect a changed degree of aëration would stand on a footing with the older method of estimating the relative amounts of organic matter present in various samples of water by the amount of oxygen absorbed by them, under certain conditions, from permanganate of potassium. If this were all the information to be got by the aëration method, it would have nothing to recommend it over the permanganate method; but on the contrary there would be much—and notably the length of time taken by an experiment—to render the examination of the aëration of a sample of water far less suitable as an analytical operation.

"Some experiments, however, which I made some time since, with sewage-polluted water, led me to the belief that observation of the changes in aëration of a water would enable us to distinguish between living and dead organic matter—a problem which no merely chemical method had so far solved. While engaged in this work a paper was published by Dr. Angus Smith (it appeared shortly before his death) in

which he also endeavours to deal with this problem by means of a chemical method. This, however, differs from my own, which I shall now proceed to describe.

"My method has been to bring the samples of water under experiment to the desired temperature (generally 20 deg. Cent.), doing this in the bottle in which it had been collected, and ensuring its being fully aërated by vigorous shaking. It was then transferred to the experimental bottle. The air used for aëration was sometimes filtered through cotton wool, but was generally taken unfiltered.

"The bottles were filled with a sample of water that was under analysis, and were then kept in a constant temperature chamber (usually at 20 deg. Cent.) for a period of several—commonly ten—days.

"In brief, I may say that the consumption of oxygen from the dissolved air of a natural water is, in the vast majority of cases, at all events, due to the presence of growing organisms, and that in the complete absence of such organisms little or no oxygen would be thus consumed."

In May, 1886, in the course of some remarks during the discussion following on a paper read by the late Dr. Tidy at the Society of Arts, Dr. Dupré said:—"There was a remarkable unanimity on the part of those who had spoken, that the dissolved organic matters, where the sewage was mixed with a certain quantity of water, would disappear rapidly as they became oxidised. He had often thought that a very good thing would be to cultivate the low organisms on a larger scale, and to discharge them with the effluent into the river, as the power which these low organisms had was remarkable."

In these observations Dr. Dupré clearly set out the line of thought upon which we had been working, and which, as it will be seen, was but a development of Dr. Sorby's conclusions some years previous. In the following January, in a paper which I read before the Institution of Civil Engineers, I pursued the point further. In discussing the question of the use of an excessive quantity of lime, for the purpose

of precipitating the solid matters in sewage, I wrote as follows:—

"One object claimed for the use of an excessive quantity of lime, and also for some other substances, is that they destroy the living organised bodies, such as bacteria, &c., which give rise to the phenomena known as putrefaction. This question is one of such vital importance to the after-character of the effluent, that it is necessary to discuss the subject at length.

"The researches of Warington have demonstrated that the process known as nitrification of the complex nitrogenous bodies existing in sewage during its filtration through land is brought about by definite organisms, who in their life processes feed upon the sewage matters and evolve the nitrogen in the form of nitric acid. As with the nitrogen, so with the carbon, which is absorbed as food and evolved as carbonic acid. Without these life processes, whether they be of an animal or vegetable nature, no destruction of the objectionable matters can take place. As the very essence of sewage purification is the ultimate destruction or resolution into other combinations of the undesirable matters, it is evident that an antiseptic process is the very reverse of the object to be aimed at. If a preservative process be required, a receptacle should be provided for the preserved matters; and in order to ensure that the antiseptic process should be a continuous one, any subsequent treatment or method of disposal must avoid the destruction of the antiseptic employed. In the case of lime, which, in the form of strong solutions, is a solvent of organic structures, what time will elapse before its neutralisation by absorption of carbonic acid and consequent loss of antiseptic properties will take place after the discharge of the effluent into running water? Obviously only a very limited period, after which the growth of organisms, so zealously destroyed, will recommence by reason of the numerous spores in the water of the river and in the air, with which it is constantly in contact; and there will thus be an end to the antiseptic properties of the system.

"The lesson to be learnt from the numerous experiments, published by various authorities, both in this country and on the Continent, is that bacteria and other low forms of organic life are most potent in the destruction of all objectionable refuse. Modern experience shows that, when this subject is better understood and thoroughly worked out, in all probability the true way of purifying sewage, where suitable land is unavailable, will be first to separate the sludge, and then to turn into the neutral effluent a charge of the proper organism, whatever that may be, specially cultivated for the purpose, retain it for a sufficient period, during which time it should be fully aërated,

BOARD OF ESTIMATE AND ...

and finally discharge it into the stream in a really purified condition. This is, indeed, only what is aimed at and imperfectly accomplished on a sewage farm. It is true that knowledge on the subject is not yet sufficiently advanced to put such a system into practical operation, but sufficient is known to show that the antiseptic treatment of sewage is the very reverse of Nature's method. The author has not the slightest doubt but that the future treatment of sewage will be a combined chemical and biological one, as suggested elsewhere by Dr. Dupré."

As may be seen from the foregoing, that suggestion was the one thrown out by Dr. Dupré a few months before, when referring to the experience we had gained during the previous three years in connection with the deodorisation of the sewage of London, and was in conformity with Dr. Sorby's views as to the cause of the disappearance of the effete matters in the river.

It will now be easily understood that in the light of these views I was enabled to recommend a simple and economical scheme for the removal of the gross solid matters, leaving the remainder for my allies, the lower forms of life, as one leaves the scraps of the domestic table for the benefit of the chicken yard.

Following the publication of these statements in 1886 and 1887, which thus clearly laid down the proposed new departure in sewage treatment, the Massachusetts State Board of Health commenced a series of experiments, and during the next three years entirely confirmed these views, as well as those relating to the principles of the chemical treatment best adapted to separate the solids from the liquid matters in the sewage. Their carefully-conducted and liberally-published experiments completed the rout of the sceptics of the biological treatment of sewage.

Valuable as were the results of the Massachusetts experiments, they still left the question in an imperfect form, as the quantity of sewage treated was too small to serve as a guide to what could be done in practice. Doubtless this

was due to their aiming at too high a degree of purification, as would happen in most laboratory experiments. It therefore became necessary that more precise data should be obtained on a working scale, and this I have had the opportunity of putting on record in connection with the experimental filter beds at the Northern Outfall Works of the London County Council from 1892 to 1896, the work since then having been ably continued by my official successor, Dr. Clowes, with results that fully confirm the truth of my earlier prophecy referred to above. If there be an exception, however, it is that the bacteria may be made to do all the work, and chemistry may stand aside, except as a handmaid in the hands of the experimentalist, to show the rate and amount of work done.

CHAPTER III.

PRECIPITATION.

THE great stumbling-block to progress for many years was the all-absorbing idea of making a profit out of sewage, which resulted in fostering the cupidity of both inventors and authorities. The sound common-sense brought to light by the labours of Royal Commissioners and others has dissipated this erroneous idea from the minds of all unprejudiced students of the question. The late Lord Bramwell and his colleagues spoke out boldly, as well they might. "Sewage disposal costs money; it involves an expense which must be met," said they. They put their feet down with all the weight of their authority upon the worn-out notion that the manurial value of sewage is to be taken into consideration as part of the general question. Where the small manurial value present in the sewage can be realised, let this be done by all means; but the primary consideration must be that of the effectual disposal of the impure flood without nuisance, and next, if possible, the reduction of the expense in those few limited cases in which surrounding conditions are favourable.

One of the most frequently misunderstood points is that of disinfection. Disinfection direct, as applied to sewage, is rarely if ever attained. Partial deodorisation is frequently and easily applied, but deodorisation *plus* purification can only be obtained by one of three methods. First, by preliminary defœcation, followed by filtration *through* large areas of suitable soil. Second, by sufficient dilution with

very large volumes of well-aërated and comparatively pure water. In this case enormous numbers of organisms rapidly dispose of the welcome food. This is naturally a simple process, but apt to fail when most required, namely, during dry and hot weather, when the supply of sufficient water fails, and the diminution of dissolved air in the water, by reason of the enormous increase of the living organisms using it at a faster rate than the water can dissolve fresh quantities of air, is such that the aërobic bacteria are displaced by the anaërobes, with their necessary accompaniment —in a stream or in open tanks—of nuisance. Third, by the direct bacteriological treatment under conditions hereafter described.

Precipitation of the solid suspended matters is an admirable and advisable proceeding as a preliminary process in certain cases, although modern experience of bacterial treatment has shown these to be very exceptional. Its misfortune is that such great things have been promised from the use of the method that its virtues are in danger of being overlooked, and the good really effected lost sight of in the oft-repeated disappointments. Chemical precipitation, so far as it is applicable to sewage, mainly effects one thing only, and that is the separation of the suspended matters from the liquid matters. Under favourable circumstances a certain percentage of the dissolved impurities may be carried down, but in no case is this fully secured. Whatever may be claimed to the contrary, there is not a workable process of precipitation yet invented which will do more than effect a separation for all practical purposes of the solid from liquid matters. That is to say, that if a thoroughly good effluent, as we now understand it, be required, the "tank" effluent, as it is called, obtained by chemical precipitation, must be submitted to further treatment. The chemist in the laboratory can certainly attain this happy result, but the expense

in actual practice would be so enormous, and therefore prohibitory, that no one would listen to such a proposal. The salts of aluminium and iron, with lime, will effect much, but their use in even preposterous quantities will not materially reduce the dissolved impurities in sewage-polluted water.

SOLUBILITY OF THE SUSPENDED MATTERS.

The solubility of a portion of the suspended matters in solutions of lime seems to have been entirely overlooked by the many writers on the subject. The results of numerous experiments made by myself, on both large and small quantities of sewage liquid, have fully demonstrated the fact that the use of an excessive quantity of lime, while affording a rapid settlement of the sludge, and a more or less clear effluent, dissolves a by no means inconsiderable quantity of the offensive matters previously in suspension, and this is apt to render the last state of the liquid worse than the first.

In proof of this statement, I would point to the following results of a special experiment made for the purpose of demonstrating the fact clearly. Carefully-washed sewage sludge was diffused in clean water, the mixture was agitated for five minutes and a sample withdrawn; an excess of lime was then added, and the mixture again agitated for another five minutes. If the action of the lime were purely one of precipitation, no increase should have been observed in the soluble organic matters previously in the water. The limed liquid, however, instead of containing less dissolved oxidisable organic matter, was found to absorb about three times the quantity of oxygen required by the unlimed liquid, the actual result being:—

Experiment to Ascertain the Effect of Lime upon Sludge.

	Oxygen absorbed from Permanganate in 4 hours.
Aqueous extract of thrice-washed sludge (filtered through paper)	0·23 grain per gallon.
The same, after the addition of lime, agitation for five minutes, and filtration through paper	0·71 ,, ,,

The well-known objectionable character of the liquid pressed from sludge, which has been treated in the usual way with lime, is a striking instance of its action on the solid matters.

This solvent action of substances used as precipitants may also be illustrated by the action of alum and sulphate of alumina upon chondrin, previously mentioned as an organic constituent of sewage. This compound is thrown out of solution by a small quantity of alum, but the precipitate is immediately re-dissolved by even a slight excess. Common salt will also effect this re-solution.

The obvious lesson to be learnt from these results is, that before any system of precipitation is adopted for a particular sewage, care should be taken to ascertain that the intended process in no way exerts a solvent action on the matters which it is desired to remove. Having determined this primary point, the next question is, "To what extent are the matters in solution affected?"

DISSOLVED IMPURITIES AND THEIR PARTIAL REMOVAL.

This point has given rise to no little controversy. Authorities on either side have differed widely, and it is only in view of the unmistakeable results obtained in the course of many experiments that I ventured to set aside all statements hitherto made on the subject, and to place on record the outcome of work specially conducted for the elucidation of this important branch of the inquiry.

It must be obvious to the most superficial observer, that in dealing with so variable a substance as water-carried sewage, results of an equally varying nature are likely to be obtained. If a large quantity of a soluble organic substance be diffused in half a pint of water, it might be thought that little trouble would be experienced in precipitating a considerable portion of it, with only a moderate quantity of the chemical agents

suitable for the purpose. On the other hand, if the same quantity of matter were diffused in several gallons of water, it would not be surprising if the desired precipitation were not so readily effected.

This consideration is not a suggestion merely, but the outcome of actual demonstration, and it explains the cause of the various contradictory statements on the subject. To exhibit the facts in a clear light, I have tabulated the results of the examination of varying samples of sewage and other solutions, both before and after treatment by the usual precipitation agents employed on sewage works (Table III.). For the purpose of ascertaining the degree of impurity present in the samples, the standard adopted is the quantity of oxygen absorbed by the organic matters from permanganate of potash, acting in an acid solution at a temperature of 80 deg. Fahr., during four hours in a closed vessel. In some cases these results have been checked by the albuminoid-ammonia process, but the former method is one peculiarly adapted for indicating the work required to be done in the ultimate purification of the objectionable matters. The various chemicals used were first dissolved in portions of the sewage treated, to avoid errors due to the apparent removal of the dissolved matters which would have been shown if the solutions had been made with clean water.

The conclusions indicated by the results given in Table III. are tolerably clear. The first portion of the table shows the results of the examination of twenty-three series, each consisting of twenty-five different effluents, obtained by as many processes, resulting from the treatment of a given sample of sewage collected from the metropolitan system. This exhaustive examination fully confirms the statement, already made, that no practical process of chemical precipitation is capable of removing more than a limited quantity of the oxidisable organic matters in solution in London sewage.

TABLE III.—*Showing the Percentage Reduction of Oxidisable Organic*
(All quantities are stated

LIQUID USED FOR EXPERIMENT.	PERCENTAGE REDUCTION OF DISSOLVED											
	1	2	3	4	5	6	7	8	9	10	11	12
Raw sewage from	Lime in solution ... 3·7	Lime in solution ... 5·0	Lime in solution ... 10·0	Lime in solution ... 15·0	Lime as milk ... 15·0	Lime in solution ... 3·7 / Iron sulphate ... 0·3	Lime in solution ... 3·7 / Iron sulphate ... 1·0	Lime in solution ... 3·7 / Iron sulphate ... 2·5	Lime in solution ... 3·7 / Iron sulphate ... 5·0	Lime in solution ... 5·0 / Iron sulphate ... 2·0	Lime in solution ... 5·0 / Iron sulphate ... 4·0	Lime in solution ... 5·0 / Iron sulphate ... 5·0
Metropolitan system	20	26	29	37	30	27	27	29	33	31	33	35
,, ,, ...	6	10	28	64	12	10	10	18	32	27	34	32
,, ,, ...	18	21	14	19	22	12	19	25	24	26	21	27
,, ,, ...	26	26	26	37	10	24	25	38	33	30	31	32
,, ,, ...	10	9	10	12	11	10	12	13	27	26	24	24
,, ,, ...	23	29	29	34	27	23	27	35	37	33	33	39
,, ,, ...	2	8	15	29	0	0	5	17	20	12	16	22
,, ,, ...	12	25	30	33	25	16	22	24	32	26	30	34
,, ,, ...	7	19	21	27	10	18	9	20	22	17	14	25
,, ,, ...	5	12	13	18	4	5	3	11	16	13	15	17
,, ,, ...	3	12	9	18	3	10	13	15	17	14	13	17
,, ,, ...	15	16	19	48	44	11	15	17	20	17	21	20
,, ,, ...	12	15	21	25	17	10	16	20	22	17	20	22
,, ,, ...	9	15	19	23	19	11	17	20	21	18	18	19
,, ,, ...	10	14	22	19	9	8	16	14	14	16	17	21
,, ,, ...	12	12	17	24	12	7	12	12	22	19	19	21
,, ,, ...	15	16	16	15	9	9	11	13	17	13	14	15
,, ,, ...	8	8	20	35	8	11	8	14	17	14	20	19
,, ,, ...	8	7	19	34	7	10	7	13	16	13	19	18
,, ,, ...	3	4	4	4	9	4	4	4	8	7	6	8
,, ,, ...	4	5	5	0	7	5	5	7	5	7	7	9
,, ,, ...	12	20	26	28	16	15	22	23	24	23	22	23
,, ,, ...	6	9	9	14	3	5	5	7	11	9	12	12
Average	11	15	19	25	13	11	13	18	21	18	19	18
Cost per annum for chemicals ..... £	13,505	18,250	36,500	54,750	54,750	15,695	20,805	31,755	50,005	32,850	47,450	54,750
Other sources	—	52	—	—	—	—	—	—	—	58	61	—
,, ,, ...	—	—	10	—	—	—	—	—	—	—	—	56

	£	s.	d.	
Lime taken as costing	1	0	0	per ton.
Sulphate of iron	2	0	0	,, ,,
Alumina sulphate	3	10	0	,, ,,

Matter in Solution by Various Methods of Chemical Precipitation. in grains per gallon.)

OXIDISABLE ORGANIC MATTER BY TREATMENT OF LIQUID WITH

13	14	15	16	17	18	19	20	21	22	23	24	25	
Lime in solution ... 5·0 Iron sulphate ... 8·0	Lime in solution ... 5·0 Iron sulphate ... 10·0	Lime in solution ... 10·0 Iron sulphate ... 10·0	Lime in solution ... 5·0 Alumina sulphate... 5·0	Lime in solution ... 5·0 Iron sulphate ... 5·0 Animal charcoal ... 5·0	Lime in solution ... 5·0 Iron sulphate ... 1·0 Alumina sulphate... 5·0	Lime in solution ... 7·0 Iron sulphate ... 1·5 Alumina sulphate ... 5·0	Lime in solution ... 10·0 Iron sulphate ... 2·0 Alumina sulphate... 10·0	Lime in solution ... 14·0 Iron sulphate ... 3·0 Alumina sulphate... 10·0	Lime in solution ... 15·0 Iron sulphate ... 3·0 Alumina sulphate... 15·0	Lime ... ... 28·0 Iron sulphate ... 6·0 Alumina sulphate... 20·0	Lime ... ... 56·0 Iron sulphate ... 12·0 Alumina sulphate... 40·0	Lime ... ... 700·0 Iron sulphate ... 100·0 Alumina sulphate...500·0	Average.
34	36	36	33	40	32	32	34	37	39	44	49	53	34
36	38	36	32	32	33	36	67	46	45	40	43	58	33
28	30	28	15	27	19	17	25	22	23	21	28	45	23
32	36	30	26	32	30	31	30	25	36	30	30	45	30
21	25	24	16	24	14	14	16	12	29	14	26	41	19
36	36	40	37	38	38	39	33	37	39	44	55	62	36
25	28	32	16	21	19	24	22	11	26	20	24	59	19
37	41	32	24	26	28	32	29	25	31	28	43	59	30
42	25	26	21	26	19	21	16	19	22	29	31	54	22
21	22	21	16	22	21	25	25	25	26	25	25	45	18
19	21	16	14	15	13	15	16	11	14	8	18	39	15
24	25	38	24	24	25	24	26	27	38	40	46	59	27
26	25	24	16	22	25	21	21	24	22	25	40	54	22
22	32	19	23	18	19	19	18	18	20	19	18	48	20
20	20	21	21	19	16	17	22	27	19	17	21	47	19
23	23	24	15	19	17	18	22	26	25	28	39	62	21
20	11	17	10	19	15	14	15	13	17	16	17	45	16
26	27	31	20	23	18	23	28	29	31	30	41	58	23
25	26	29	19	22	17	22	26	18	29	29	40	55	20
8	10	10	0	7	7	11	12	13	12	13	29	58	10
9	7	11	0	12	11	12	13	14	11	13	16	44	10
26	22	23	22	20	20	20	22	21	25	22	33	59	23
14	13	14	10	10	11	28	18	12	12	14	19	50	17
25	25	30	18	22	20	22	24	21	26	24	31	52	—
76,650	91,250	109,500	82,125	237,250	89,425	100,375	178,850	200,750	268,275	401,500	803,000	9,672,500	—
61	69	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	33	—	—	—	—	—	—	—	—	—	—

Volume of sewage taken at 156,800,000 gallons per day.

The results further demonstrate the striking superiority of iron over alum for sewage purification. By the use of iron sulphate in conjunction with lime, as much work is effected (on the basis of the London sewage) for 31,000*l.* per annum as would be obtained by an expenditure of 82,000*l.* for alum and lime. Even when lime and alum, with the help of only one-twentieth of their weight of iron sulphate, were used to an extent of 178,000*l.* per annum, not so much work was accomplished as by an expenditure of only 54,000*l.* for lime alone when used in solution. Alum is valuable chiefly for its effect in removing some of the colour from the effluent, and thus appealing to the eyesight; while the matters actually dissolved are there nevertheless. The observations with regard to the action of alum upon chondrin already made will help to explain this. The experiments with animal charcoal—column 17—show that if this substance were used to an extent of 182,500*l.* per annum the benefit would be practically *nil*. The table also indicates most clearly the danger of drawing conclusions from the examination of one or two samples only.

The second portion of the table gives some results which will explain the remarkable differences of opinion expressed by various authorities as to the percentage reduction of dissolved solids by various processes, when acting on sewage of a character different from that of London. The sewage used for this purpose was obtained from other sources, and was evidently of such a character that the oxidisable dissolved solids were readily precipitated by even a small quantity of lime in solution, viz., 5·0 grains, no less than 52 per cent. being removed. The addition of an iron salt to the limed sewage effected a total reduction of the dissolved oxidisable matters of 61 to 69 per cent.

In order to test this point further, and to show that no benefit is derived from the use of an excessive quantity of

chemicals, the results of a series of precipitation experiments on solutions of clear mutton extract are given in Table IV. The results show that the same quantity of precipitant is capable of removing from 46 to 90 per cent. of the total oxidisable matter, according to the strength of the solution, and that a very large increase in the quantity of the chemicals used affords no advantage whatever, the results being practically the same, the differences, such as they are, being in favour of the smaller quantity of re-agents employed.

It is thus seen that statements which have hitherto met with a great deal of scepticism on either side may be perfectly correct, the difference being solely due to the variable nature of the sewage operated upon.

These various considerations unquestionably point to the general conclusion that where it is intended to treat the sewage by chemical means, the following rules should, as far as practicable, be observed, viz. :—

(1) That the sewage should be diluted as little as possible.

(2) That the flow of sewage should be adjusted so that the agitation of the particles in suspension should be of a minimum character.

(3) That, unless absolutely necessary, no pumping should take place before precipitation.

[*Table IV.*

Table IV.

Percentage reduction of Oxidisable Organic Matter in a Solution of clear Mutton Extract by Chemical Precipitation, as estimated by the Absorption of Oxygen from Permanganate of Potash in Four Hours acting at a temperature of 80 *deg. Fahr. in closed vessels.*

SOLUTION USED.	Oxygen absorbed by untreated solution.	Percentage reduction of dissolved matters by treatment of liquid with		
		Per gallon. 8·7 grains lime 1·0 grains sulphate of iron	Per gallon. 7 grains lime 5 grains sulphate alumina 1 grain sulphate iron	Per gallon. 14 grains lime 10 grains sulphate alumina 2 grains sulphate iron
Solution containing :	Grains per gallon.			
20 p.c. of clear mutton extract	100·0	90·3	90·1	91·2
10 ,, ,, ,, ,,	50·0	87·2	87·0	—
5 ,, ,, ,, ,,	25·0	86·7	86·6	—
3 ,, ,, ,, ,,	15·0	83·5	82·5	—
1 ,, ,, ,, ,,	5·0	82·2	81·2	—
0·5 ,, ,, ,, ,,	2·5	78·4	76·4	—
0·2 ,, ,, ,, ,,	1·0	59·0	55·0	—
0·1 ,, ,, ,, ,,	0·5	56·0	46·0	—

The consideration of these results leads to the inevitable conclusion that excessive expense in striving to attain the impossible, viz., perfect purification of sewage liquid by

chemical precipitation, is not permissible. The minimum cost at which a fair separation of the liquid from the solids can be effected should be aimed at. The money so saved will be spent to far better purpose in constructing porous filter beds for the final purification by bacterial action, as previously pointed out.

As showing the character of the matters obtained from ordinary water-carried sewage after they have been pressed in the form of "cake," the following table will be of interest:—

TABLE V.

Average Composition of Pressed Sewage-Sludge from Crossness.

	Per cent.
Moisture	58·06
Organic matter	16·69
Mineral	25·25
	100·00

The organic matter contains—

	Per cent. on pressed sludge.	Per cent. Nitrogen.
Saline ammonia	0·035	0·87
Organic nitrogen, calculated as ammonia	1·025	

The mineral matter contains—

	Per cent.
Carbonate lime	7·94
Free lime	2·45
Silica	8·08
Oxide of iron	0·97
Oxide of aluminium	3·39
Phosphoric acid (= phosphate lime 1·44)	0·658
Magnesia	traces

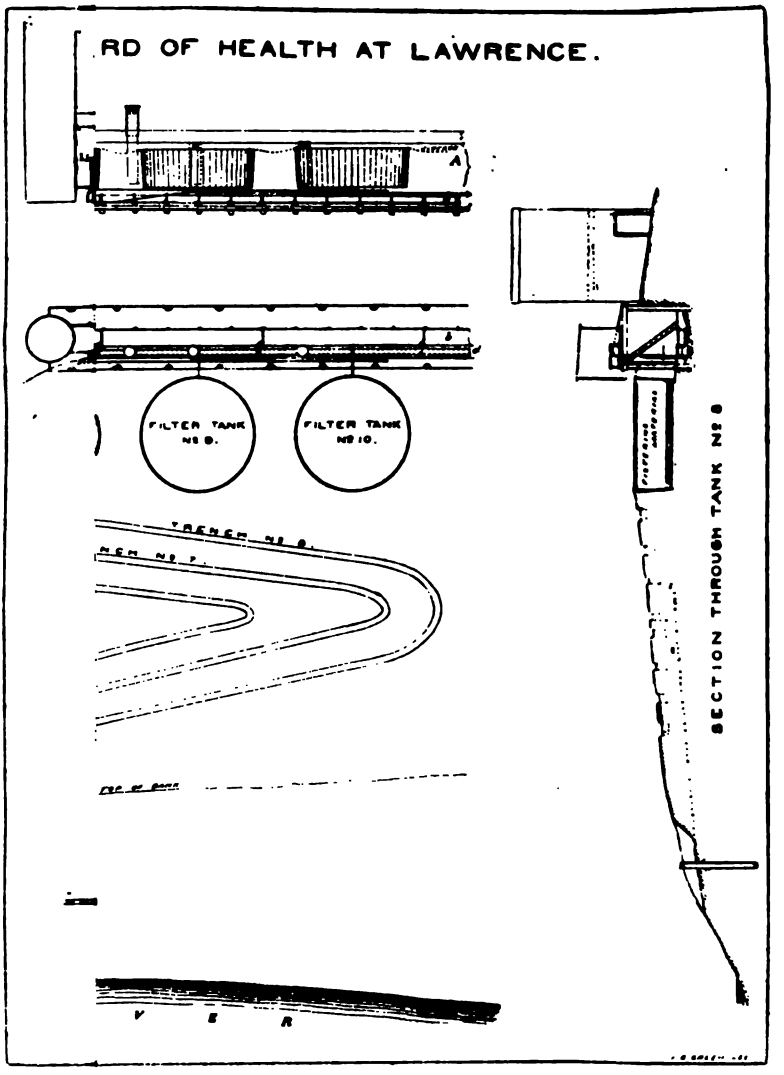
CHAPTER IV.

EXPERIMENTS AT MASSACHUSETTS AND LONDON.

We may now proceed to discuss the experience gained up to the present time. It will be advisable first to consider very carefully the various experiments which have been made in America and in England. As shown in the second chapter, I pointed out in 1887 that without the intervention of living organisms no material destruction of the complex bodies existing in sewage could take place. This was the fundamental idea underlying my work in connection with the purification of the Thames.

Following the publication of these views, the State Board of Health of Massachusetts commenced their series of elaborately-conducted experiments in November of the same year, and during the years 1888, 1889, and 1890 obtained very valuable results. So thorough were these that no apology is needed for including a *résumé* of them.

The filtering grounds were situated in the east part of the city of Lawrence, on the north bank of the Merrimac River, and comprised about two-thirds of an acre. On the north side of the grounds was a building 300 ft. long and about 10 ft. wide and 10 ft. high, nearly all below the surface of the ground, and lighted by windows in the roof. Running lengthwise through the building was a drain, and above this an open wooden conduit, about 2 ft. wide, and 1 ft. high, resting on piles, and sloping with the building, viz., 1 ft. in 100 ft. This conduit was divided at each 25 ft. of its


RD OF HEALTH AT LAWRENCE.
FILTER TANK No 9.
FILTER TANK No 10.
SECTION THROUGH TANK No 9

To face p

length by a tight partition. Each section thus formed was used as a measuring basin, being 25 ft. long, about 2 ft. wide, and 1 ft. high, and holding between 200 and 300 gallons, and had an outlet by which the contents might be turned into the drain beneath.

Outside of the building, where the surface of the ground is 7½ ft. above the top of the measuring basins, were ten large wooden tanks, sunk their full depth into the ground.

These tanks, numbered one to ten, were made of cypress, circular in plan, 16 ft. 8 in. in diameter inside at the bottom, 17 ft. 4 in. at the top, and 6 ft. deep inside. They were set with the bottom sloping 4 in. towards the building.

In each tank an underdrain, 15 ft. in length, of horse-shoe section of about two square inches in area, was set with open part downwards, and half an inch above the bottom, resting on blocks 6 in. apart, and the floor was covered with one layer of coarse gravel stones, about 1 in. by 2 in., this by another layer of smaller size, upon which followed layer upon layer of gravel, decreasing in size to ⅛ in. in diameter, and making a thickness of 3½ in. This fine gravel was covered with very coarse mortar sand, with top surface level, 3½ in. deep in the middle of the tank. Above this substratum, which was the same in all the tanks, the several tanks were filled as follows:—

Tank No. 1.—Filled 5 ft. in depth with very coarse clean mortar sand.

Tank No. 2.—Filled 5 ft. in depth with very fine, nearly white, sand.

Tank No. 3.—Filled with peat from a cultivated field, 4 ft. in depth including the previously undisturbed lower layers, and covered 1 ft. in depth with the original top layer.

Tank No. 4.—Filled 5 ft. in depth with river silt, being mostly a very fine sand.

Tank No. 5.—Filled 5 ft. in depth with a good quality of brown soil, taken in the autumn from a garden which had been manured and cultivated that season.

Tank No. 6.—Filled 3 ft. 8 in. in depth with coarse and fine sand and gravel.

Tank No. 7.—Filled 3 ft. 8 in. in depth with the same as No. 6, above which were 10 in. of yellow sandy loam, and 6 in. of brown soil.

Tank No. 8.—Filled 3 ft. 8 in. with the same as No. 6, above which were 8 in. of yellow sandy loam like that in No. 7, and this was covered with 8 in. of sand and gravel like that beneath the loam.

Tank No. 9.—Filled 4 ft. 3 in. in depth with a very compact hard pan of clay, sand, and gravel, covered with 9 in. of brown soil.

In each case the filtering material was thrown from the shovel, scattering into water which partly filled the tank. After filling each tank to the height given, which was generally 3 in. below the top of the tank, a little sloping bank 1 ft. wide was filled around the inside of each tank to prevent the liquid applied reaching the side of the tank too freely. The area of the surface to which sewage was applied and the effective area of the filtering material were regarded as being $\frac{1}{100}$ of an acre.

Tank No. 10 had been used for the measurement of the rainfall and the evaporation.

From the end of the underdrain, at the lowest point in the bottom of each tank, extended through the bottom a short brass pipe 2 in. in diameter connected by a quarter turn to a 2-in. iron pipe, which, passing through the ground and into the building, conveyed drainage from within the tank to its measuring basin, where the quantity was read on a scale indicating gallons.

During November and December, 1887, water from the city mains was applied to the several tanks. Sewage had been brought to the building in a 2½-in. pipe of galvanised iron from a point in the main sewer of the city about 1,000 ft. above its outlet, and above the entrance of the streams from the manufacturing establishments. This liquid, from perhaps ten thousand people, may be regarded as ordinary city drainage, similar during very dry weather to sewage separate from storm water, but during wet weather very much diluted by surface drainage.

The sewage was raised by means of two pumps into two measuring basins within the building at a higher level than the top of the filtering tanks, where the quantity to be put upon any tank was noted by a scale of heights indicating gallons, and was distributed by movable hose to either of five tanks from one measuring basin, and to the other five tanks from the other measuring basin.

Besides these large filtering tanks there were placed within the building ten galvanised iron tanks, having about the same depth, but a diameter of only 20 in., giving an area of surface of one-hundredth of that of the large tanks, or one twenty-thousandth of that of an acre. These tanks were numbered 11 to 20. They were filled with various materials, such as sand, &c., as with the larger ones.

All the large tanks and the trenches were exposed to snow and rain through the first winter and summer, and until November 20th, 1888, when tanks numbered 1, 2, 4, 5, 6 and 7 were covered with canvas, and trenches numbered 5, 6, 7, and 8 were covered with boards to keep out the snow. The canvas coverings were removed March 13th, 1889.

The experimental station at Lawrence was arranged, and the experiments conducted, for the purpose of determining the fundamental principles of filtration not previously established, and to learn what can be accomplished practically by filters

made of some of the widely varying materials found in suitable localities for filtration areas, that there may be deduced from these results the probable efficiency of other materials to be found throughout the State.

About four thousand chemical analyses of the sewage applied to the tanks and of the filtered effluent were made in the twenty-two months. Observations upon the number of bacteria living in the sewage and in the various effluents were made during the two years, and examinations were made of the microscopic organisms.

Thus equipped, the officers of the Board proceeded to conduct a series of experiments of the most elaborate and valuable character, and those who desire to follow them in detail should procure or obtain access to the reports of that Board for the year 1890, as the included abstract can only point out the general nature of the work and the conclusions at which they arrived. In the "General View of Results" the Board reported as follows:—

"We have now filtered sewage intermittently through clean gravel stones, larger than robins' eggs, through filters made of various grades of gravel and sand, to a sand whose particles average but 0·004 in. in diameter—a fine granular dust—as well as through soils and peat. With the gravels and sands, from the coarsest to the finest, we find that purification by nitrification takes place in all when the quantity of sewage is adapted to their ability and the surface is not allowed to become clogged by organic matter to the exclusion of air.

"With fine soils, containing, in addition to their sand grains, 2 or 3 per cent. of alumina and oxide of iron and manganese and 6 or 7 per cent. of organic matter, we find that, when only 6 in. in depth, resting upon fine sandy material, they retain water so long that the quantity that can be applied is so small, and the interval in which this must settle and drain away to allow air to enter the field is so long, that the amount of sewage that can be purified is very small. When the quantity applied is adapted to its ability, such a filter may give excellent results, quite free from bacteria.

"With greater depth of soil the quantity that can be filtered will evidently become less; and, with the depth of 5 ft. of such a soil, we have found that nitrification did not take place; and, although it was probable that no bacteria came through, the organic matter in the effluent was at the end of two years nearly as great as in the sewage. This soil remained continually so nearly saturated that, when only 5,000 gallons per acre were being filtered daily, although free to drain over every square foot of the bottom, sufficient air could not be taken in to produce nitrification; and the chemical result with this material was, throughout the two years of its trial, nearly the same as would be expected if the filtration had been made continuous instead of intermittent.

"With peat upon the surface of a filtration area, even to the depth of only 1 ft., its imperviousness to liquid, and the quantity that it will retain until it evaporates, renders intermittent filtration impracticable; and a sand area thus covered with peat can be rendered efficient for filtration only by the removal of the peat from the surface.

"The experiments with gravel stones give us the best illustration of the essential character of intermittent filtration of sewage. In these, without straining the sewage sufficiently to remove even the coarser suspended particles, the slow movement of the liquid in thin films over the surface of the stones, with air in contact, caused to be removed for some months 97 per cent. of the organic nitrogenous matter, a large part of which was in solution, as well as 99 per cent. of the bacteria, which were, of course, in suspension, and enabled these organic matters to be oxidised or burned, so that there remained in the effluent but 3 per cent. of the decomposable organic matter in the sewage, the remainder being converted into harmless mineral matter.

"The mechanical separation of any part of the sewage by straining through sand is but an incident, which, under some conditions, favourably modifies the result; but the essential conditions are very slow motion of very thin films of liquid over the surface of particles having spaces between them sufficient to allow air to be continually in contact with the films of liquid.

"With these conditions it is essential that certain bacteria should be present to aid in the process of nitrification. These, we have found, come in the sewage at all times of the year; and the conditions just mentioned appear to be most favourable for their efficient action, and at the same time

most destructive to them and to all kinds of bacteria that are in the sewage.

"The coarse sand filtered 117,000 gallons per acre per day for three months, after which the quantity was increased, and averaged for five months 177,000 gallons per acre per day. The purification was less complete for the first month after the change, but in the second and third months it was more complete than with the quantity given above. The fourth and fifth months, however, gave less satisfactory results, showing that the filter was becoming overburdened, and the surface became much clogged with organic matter. The filter was evidently overworked. The other filters, filtering quantities decreasing with their perviousness from 60,000 gallons per acre per day to 9,000 gallons, indicated that they would continue giving as good results indefinitely.

"The results of experiments as to the effect on filtration of exclusion of air, *i.e.*, by continuous instead of intermittent filtration, was that no nitrification takes place, and the effluent gradually becomes worse until it contains as much organic matter as the sewage."

London Experiments.

Valuable as were these results, they still left the question in an all but impracticable form, as the quantity of sewage thus treated was so small. Doubtless this was due to the use of too fine filtering materials, and the high degree of purification attained. It therefore became necessary that precise data on a working scale should be obtained; and, with this object, the Main Drainage Committee of the London County Council instituted a series of experiments at the Northern Outfall Sewage Precipitation Works with most successful results.

Before proceeding further, it may be interesting to point out that the general results fully confirm the opinion already quoted, and expressed by myself in 1887, as to the biological treatment of a chemically treated sewage; the only departure from the suggestion previously made being

that, instead of its being necessary to feed the sewage with any specially prepared organism, we then knew that the sewage already contained these in abundance, and that all that was required was to give them free scope under favourable conditions to enable them to fully exert to any extent that may be desired their special function of breaking up the organic matters. Later experience, however, has shown that by proper preliminary sowing with suitable bacteria, a filter may be more speedily prepared in its best working condition, but there appears to be no practical advantage in adopting this course.

The experiments made under my direction at the Main Drainage Works at Barking Creek may be conveniently divided into two main groups, viz. :—

(1) Experiments with small filters using various filtering materials.

(2) Experiments with a one-acre filter, using coke breeze only as material.

The latter may again be sub-divided into—

(*a*) Preliminary trials on velocity of passage, &c.
(*b*) Experiments on biological lines.
(*c*) Experiments with doubled means of filling.
(*d*) Experiments with increased facilities for emptying.
(*e*) Experiments on recuperative power.

Series No. 1.

The tanks for filters used in the first series of experiments were built of wood, and were each equal in area to $\frac{1}{200}$th part of an acre. They were four in number, and were filled with pea ballast, coke breeze, burnt clay, and a proprietary material (with gravel and sand) respectively. All four were worked at the same rates and during the same hours. During the first six weeks sewage effluent was passed through at the

rate of 500 gallons per square yard per day, but from the middle of July to the end of August the rate was reduced to one-half, or 250 gallons per square yard in twenty-four hours. The filtration was intermittently continuous, the filters passing effluent constantly for eight hours daily and resting during the remaining sixteen hours, being allowed to run dry at the end of each day's work. The outlet valve was closed just sufficiently to keep the filters full, the effluent being level with the surface of the filter material.

The whole quantity of effluent passed through amounted to 185,000 gallons, in a total of 2,160 hours, of which the filter worked 484 hours and rested empty 1,676 hours. The average rate, therefore, inclusive of rest periods, was 411,000 gallons per acre in twenty-four hours.

Filter No. 1. Burnt Ballast.—The material for this filter was obtained by burning clay taken from the marsh land adjoining, and was placed in the tank to a depth of 4 ft.

The purification effected by this filter was less than that attained by any of the remainder. The clarification was also less than in the case of the pea ballast and proprietary filters, being exactly the same as effected by the coke breeze. This was undoubtedly owing to the extreme looseness and porous nature of the materials. The filtrate was free from putrefactive odour, remaining sweet for many months in either stoppered or open bottles.

Filter No. 2. Pea Ballast.—This filter was filled with Lowestoft shingle, of pea size. The clarification effected in the filtrate was 75 per cent. more than in the case of the burnt ballast. The purification was also greater, the reduction of oxidisable organic matter amounting to 52·3 per cent.

Filter No. 3. Coke Breeze.—This filter was filled with coke breeze to a depth of 4 ft., and 3 in. of gravel were placed on the top to prevent the coke from floating. As far as clari-

fication was concerned, this filter produced equal results with the burnt ballast; but the purification effected was higher than in the case of any of the other materials, the reduction of the oxidisable organic matter in solution amounting to 62·2 per cent. No renewal of the material was required.

Filter No. 4. Sand.—This filter, having an area of 16 square yards, or $\frac{1}{300}$th of an acre, was filled with gravel, walnut size 5 in., bean size 2½ in., pea size 1½ in., and sand 10 in., taken in order from below upwards. It formed part of the compound proprietary filter. The rate at which effluent was passed through was one-half more per square yard than in the case of the other filters, the sand filtration being a preliminary to and part of the treatment by the proprietary article, and the areas of the two portions being together equal to one of the remaining filters, already described.

The clarification effected was much greater than in the case of Nos. 1, 2 and 3; but the purification, measured by the reduction in the amount of oxidisable matter in solution, was considerably less than in the case of the coke breeze, somewhat less than by the pea ballast, and practically the same as by the burnt clay. On two occasions the filtrate became slightly putrid, the results thereby differing from those obtained from any other filtering material employed. Doubtless this tendency to become putrid was to a great extent due to the deficient aëration of the interior of the filter, in consequence of the capillary attraction of the finer particles of sand holding the water, and thus choking the pores when the filter was emptied. This filter had to be repeatedly raked and cleared, and 2½ in. of sand were removed and replaced by new on the 11th of July.

No. 5. Proprietary Filter.—This filter had an area of 8 square yards, and was filled with 3 in. of gravel, walnut size; 2 in. gravel, bean size; 1½ in. gravel, pea size; 1 in.

sand, and 12 in. of the proprietary material; taken in order from below upwards.

The effluent which it received had already passed through filter No. 4 (sand), and had thus been greatly clarified, whilst the dissolved impurity had been removed to the extent of 42 per cent. The rate of filtration was three times that of the other filters, so as to bring up the rate of the combined filter to an equality with the rest. The filter was supplied with perforated pipes leading to the surface for aëration. In general appearance the filtrate from this compound filter was slightly superior to all the others, the clarification effected being a little more than in the case of the sand forming the first portion. The purification effected by this process of double filtration amounted to 61·6 per cent., a figure practically the same as was obtained by the use of coke breeze. None of the filtrates showed any signs of putrescence when kept for lengthened periods in either open or closed bottles.

TABLE VI.

Description of filter.	Average oxygen absorbed in four hours. Grains per gallon.		Average albuminoid ammonia. Grains per gallon.		Average purification effected, as determined by oxygen absorbed.
	Crude effluent.	Filtrate.	Crude effluent.	Filtrate.	
					Per cent.
Burnt ballast.....	1·881	1·072	0·243	0·125	43·3
Pea ballast.....	1·881	0·880	0·257	0·142	52·3
Coke breeze	1·881	0·711	0·262	0·103	62·2
Sand	1·725	1·001	0·250	0·132	42·0
Proprietary filter	1·881	0·721	0·267	0·106	61·6

In Table VI. are given the results of numerous analyses made in each case during the months of June, July, and August, 1892.

From the results obtained it appeared that a considerable amount of purification could be effected by any filtering material, the desiderata evidently being porosity and consequent power of re-absorbing atmospheric oxygen. For foul waters sand proved too fine, whilst the burnt ballast used was too coarse. Coke breeze seemed to unite the necessary qualifications, and as it is also a cheap material it was selected for the further trials on a large scale. There can be little doubt, however, that the question of cost of material should be allowed to decide what should be used for a filter in any given place, since burnt ballast or gravel may be made much more effective by using a greater depth of more finely-granulated material, combined with a slower rate.

In the course of the above experiments, numerous gelatin plate cultivations were made to ascertain the effect of filtration upon the number of micro-organisms present. The number in the tank effluent before filtration, and in the filtrates, was found to vary very considerably, those in the filtrate generally being present in larger numbers; but it soon became apparent that the presence of comparatively fewer or more microbes afforded no indication of the degree of purification effected, the main point being that the presence of a large number of organisms was evidence of the activity of the process of splitting up the organic compounds in the sewage matters passing through the filters. A considerable reduction or a practically complete removal of organisms might have been effected by the use of a finer-grained material and slower filtration; but the object held in view during the experiments was the attainment of the highest degree of speed consistent with such purification as would

remove all objectionable characters such as odour, colour, and liability to putrefaction.

Series No. 2.

In the second series of experiments a filter was constructed covering one acre of land. The ground was levelled, and embanked where necessary, and perforated drains were laid, meeting in a common trunk for discharge. The filtering material consisted of 3 ft. of pan breeze covered with 3 in. of gravel.

(a) In the first part of the series under notice, the special object of the experiments was rather the ascertaining of the rate at which it was possible to pass effluent through the filter, and not the manner of producing the best results. The filter, however, speedily became clogged, and after the sixth week all the filtrates were putrid. The daily quantity that could be passed decreased rapidly, until at the end of twelve weeks the filter was quite useless, being putrid throughout. Valuable information was thus gained: for it was shown that rest and aëration are vital, and also that, in order to obtain the best work from a filter, the quantity poured on it must increase very gradually, so as to permit of the proper biological condition being reached. The rate of working varied from close on one million to a quarter of a million gallons per diem. The filling was during several weeks continued until the water stood 6 in. above the surface; when the filter was emptied the top portion ran through without having time for purification, and thus doubtless aided greatly in reducing the efficiency of the filter during this set of experiments.

ONE ACRE FILTER BED AT THE NORTHERN OUTFALL WORKS, BARKING CREEK.

[*To face p.* 58.

The analytical results obtained during this period are given in Table VII.

TABLE VII.

DATE.	Average oxygen absorbed in four hours. Grains per gallon.		Average albuminoid ammonia. Grains per gallon.		Average nitrogen as nitrate. Grains per gallon.		Average purification effected on oxygen absorbed.
	Effluent.	Filtrate.	Effluent.	Filtrate.	Effluent.	Filtrate.	
1893.							Per cent.
28th Sept. to 6th Oct..	3·631	2·128	—	—	0·000	0·083	41·0
9th Oct. to 13th Oct. ..	2·884	0·509	—	—	0·029	0·215	82·0
16th Oct. to 20th Oct..	3·295	0·502	—	—	0·029	0·117	85·0
23rd Oct. to 30th Oct..	3·915	1·447	—	—	0·103	0·021	63·0
30th Oct. to 6th Nov...	4·420	1·546	—	—	0·000	0·000	65·0
6th Nov. to 13th Nov..	4·404	1·285	0·394	0·110	0·283	0·203	71·0
13th Nov. to 20th Nov.	4·122	1·125	0·368	0·097	0·299	0·317	73·0
20th Nov. to 27th Nov.	4·336	1·203	0·403	0·091	0·304	0·241	72·0
27th Nov. to 4th Dec..	4·832	1·135	0·457	0·119	0·180	0·175	77·0
4th Dec. to 8th Dec. ..	4·745	1·070	0·435	0·109	0·077	0·080	77·0
11th Dec. to 18th Dec..	3·821	0·979	0·401	0·092	0·021	0·130	76·0
19th Dec. to 23rd Dec..	4·877	1·387	0·393	0·191	0·000	0·000	71·6

(b) The first series of experiments on biological lines, conducted with the same filter as the preceding, was then commenced. The surface was raked, and the bed was allowed to rest during three and a half months. For fully three months of that time a putrid odour was observable when the filter was disturbed, but this gradually disappeared, and during the last fortnight the coke breeze was perfectly sweet. From that time the filter was kept practically constantly at

work for nearly a year, the only rest of any length being from the 17th November, 1894, to the 2nd January, 1895, when facilities for more rapid emptying were made in the arrangements.

The process adopted was to begin with small quantities, the filter being filled and emptied only twice daily, with a view to getting it into the necessary bacterial condition. This was commenced on the 2nd April, 1894, and continued for a few weeks, the purification effected gradually rising. The quantity of effluent passed was about 500,000 gallons per diem, and the purification between 70 and 80 per cent. The highest state of efficiency was reached on the 3rd May, or after a full month's working. The purification reached 83 per cent., and fish placed in the filtrate lived for many weeks. In fact, fish (minnows, &c.) came up the ditch by which the filter was emptied to the very mouth of the outlet.

(c) Alterations were then made in the arrangements for filling, the feeding trough being doubled. The daily quantity was increased to over 600,000 gallons, the analytical results continuing to be highly satisfactory, as shown by the averages of the daily analyses from August 3rd to November 9th, 1894.

(d) Towards the end of 1894 the emptying arrangements were supplemented by a pump to prevent tide-locking, and later the resting time was shortened, until finally the filter passed $1\frac{1}{6}$ million gallons daily for six days, resting empty from 10 p.m. on Saturdays until 6 a.m. on Mondays. The method adopted was to fill the filter to just level with the surface, requiring an average time of two hours, allow it to remain standing full for one hour, the emptying occupying an average of five hours, thus completing the cycle in eight hours. Working in this way, the filter passed an average of 1,000,000 gallons a day, including all times of

rest, during a period of eight weeks, the filtrates being clean and sweet, and the purification effected 78 per cent. Nitrification proceeded satisfactorily, and the filter was apparently capable of continuing for an indefinite time.

A point of the greatest importance is the fact that the filter was able to do its work satisfactorily during the exceptionally severe weather in January and February, 1895. A thin coat of ice was formed on the surface, but the filtration proceeded without intermission, the only noticeable change being the decreased production of nitrates.

(e) After the filter had been successfully dealing with 1,000,000 gallons daily for about eight weeks, a large quantity of sludge, amounting to at least ten tons, was run upon it accidentally. This occurred during the week ending 23rd February. The result was an immediate falling off in the quality of the filtrate; a putrescent odour was observed, and finally the filter had to be thrown out of work. Remarkable evidence of the recuperative power of the coke breeze was, however, obtained, as after twenty days' rest it was quite sweet again, nothing objectionable being observed on digging down to a depth of about 2 ft. The coke had only the odour of ordinary earth when moist, and on being burnt gave no objectionable smell. On resuming work, twenty-eight days after resting, satisfactory results were again obtained.

From this time until the end of September in the same year the filter was kept continuously at work (except during one week in August) on the same system, viz., alternate filling, resting full, and emptying, with twenty-four hours' entire rest each week. The results are shown in the following table; the figures given are averages of daily analyses, each sample being a mixture of quarter-hour samples from each filling and emptying.

effluent and the filtrate respectively, amounted to 250 tons; making, with the 110 tons of suspended organic matter, a total of 360 tons. The organic matter that remained in the filtrate was in such a condition that no signs of after-putrefaction were exhibited, however long the filtrate was kept, either undiluted or diluted, in open or closed bottles.

From these results it appears that the action of a bacteria bed, or so-called "filter," is two-fold. (1) It separates mechanically all gross particles of suspended matter, and renders the effluent clear and bright. (2) It effects the oxidation of organic matters, both those in suspension and those in solution, through the agency of living organisms. It is the establishment and cultivation of these organisms which is to be aimed at in the scientific process of purification by filtration.

Three conditions are essential. First, there must be a suitable contact material which attracts and retains the organic matter; secondly, the organisms must be supplied with plenty of air; and, thirdly, there must be present a base, such as lime, with which the nitric acid can combine. Filtration on biological lines of sewage or other foul water, containing in solution but little free oxygen and a large quantity of oxidisable organic matter, therefore means:—

(1) That the filter, by cautious increments in the quantity of effluent, which in itself contains the necessary organisms, must be gradually brought to a state of high efficiency, which condition will be shown by the existence in the filtrate of nitric acid in the form of nitrates.

(2) That the contact of the micro-organisms with the effluent to be purified must be effected by leaving such effluent to rest in the filter for a greater or less time, according to the degree of purification required, the process being analogous to that of fermentation.

(3) That after each quantity of effluent has been dealt with the micro-organisms must be supplied with air, which is readily effected by emptying the filter from below, whereby air is drawn into the interstices. The filter must stand empty for an hour or more previous to another filling, and a longer period of aëration, say twenty-four hours, must be allowed every seven or eight days.

The life of a coke-breeze filter worked in this way is practically without limit.

From the general results obtained by these several trials under various actual working conditions, it is apparent that there is no difficulty in obtaining any desired degree of purification by means of a system of filtration conducted on biological principles. If a higher degree of purity be required than that indicated by the foregoing, it can be obtained by an augmentation of the filtering appliances at a comparatively small cost, as, where clay is obtainable, the method of construction employed in making the new burnt ballast filter bed at Sutton, Worcester Park, Harrow and elsewhere may be adopted, viz., by simply digging out the clay to form a pit about 3 ft. deep, and filling it up with the same clay after thorough burning, and thus a cheap and efficient filter bed is obtained, the cost of the large filter bed at Sutton, having an area of 4,454 square feet, or rather more than one-tenth of an acre, being less than 100*l.*, including all charges.

By such a system the necessity for costly farms is entirely obviated. The results are completely under control, and the filters can be arranged to suit all necessary requirements.

Continued Experiments with London Sewage.

Such was the position in 1897 when I resigned the post of chemist to the London County Council and

Dr. Clowes was appointed as my successor. After inspecting and carefully considering the operations at the outfalls in the Thames he arrived at the conclusion that the work in connection with the bacterial treatment of the London sewage should be continued. This was sanctioned by the Main Drainage Committee, and Dr. Houston was retained to carry on the bacteriological investigations. After three preliminary reports, Dr. Clowes finally reported on the 17th April, 1902, in favour of the adoption of the system of bacterial treatment. The following extracts from this valuable report* will be read with interest:—

At the time of my appointment as chemical adviser to the Council, the results arrived at by my predecessor were so promising that I strongly recommended their continuance on an extended scale; and for four years, with the assistance of the chemical staff and with the co-operation of the superintendents at the outfalls, I have conducted this experimental purification of the sewage effluent, and have arrived now at results and conclusions which I am convinced are of the greatest importance, and are worthy of the most serious consideration of the committee and of the Council.

Description of the Bacterial Experiments.

When I recommended the committee to continue the experimental treatment, there was a large bacterial coke-bed, one acre in area, at the Northern Outfall which was dealing with a small portion of the present effluent before it entered the river. This bed was arranged only to treat the chemical effluent; it was not of satisfactory construction, nor was it filled with suitable coke material. Further, it was impossible, owing to its low level, to empty it at all states of the tide, and accordingly it could not be filled as often as was necessary, in order to obtain the knowledge which was required. At the desire of the committee, however, this bed has been maintained in action for over eight years, and it is now still giving admirable results in purifying the present sewage effluent.

But with the sanction of the committee, I have had in constant operation, and under most careful observation, a series of smaller coke-beds. These beds have received a special supply of raw sewage which

* Report to the London County Council by the Chemist, April 17th, 1902. No. 603.

came direct from the main sewer, and was entirely unmixed with chemicals. The process of working these beds has been subject to constant improvements and extensions, which have been suggested by experience and observation. I will only here describe the final method of experimental treatment which has been adopted.

The raw sewage, which has been screened from its coarser matters only, is pumped continuously into a settling tank, the rate of supply being so adjusted to the capacity of the tank that the sewage remains about six hours in the tank before it flows away through an elbow pipe from beneath the surface of the liquid into the coke-beds.

In this tank practically the whole of the suspended or floating particles of the sewage settle as sludge, and are allowed to remain undisturbed. It is found that a considerable proportion of this sludge disappears by bacterial action. During the first period of six months, before the bacterial action was fully started, 25·6 per cent. of the sludge disappeared, and during a subsequent similar period more than 50 per cent. of the sludge was removed by bacterial action. The portion which disappeared was the most putrescible portion of the sludge, which is at present carried to sea in the Council's sludge boats. Its disappearance would reduce the freight which these boats are required to remove. But it is probable that a considerable further reduction in the "sludge" cargoes might be effected by properly devised detritus settling tanks in which road sand would subside, and from which it might be removed to the marshes without giving offence. This reduction in the amount of sludge, which is secured by bacterial action alone, would be of the greatest importance.

The sewage as it flows from the settling tank is less pure than the effluent which is at present discharged into the river at Crossness, and is quite unsuitable for direct discharge into the stream. But by the subsequent coke-bed treatment it is rendered sufficiently pure to support the life of fish, and to insure it against undergoing even in summer time any offensive change.

In the experimental treatment, the settled sewage is therefore allowed to flow into a coke-bed, which is a tank filled with suitable coke fragments to a depth of six feet. As soon as the bed is filled to the surface of the coke the supply is stopped, and the sewage liquid is allowed to remain in contact with the coke for two hours. It is then drained off from the bottom of the bed, and constitutes the "bacterial effluent." After the liquid has flowed away, the coke-bed remains empty for two hours, and is then refilled with a fresh supply of the settled sewage, which is treated in precisely the same way as the preceding charge. The coke-bed receives and purifies four charges of settled sewage in the twenty-four hours.

Conclusions arrived at by the Experimental Treatment.

The points which have been established by the experimental work are the following :—

1. That by suitable continuous undisturbed sedimentation the raw sewage is deprived of matter which would choke the coke-beds, and the sludge which settles out is reduced in amount by bacterial action to a very considerable extent. This reduction might undoubtedly be increased by the preliminary removal of road detritus.
2. That the coke-beds, after they have developed their full purifying power by use, have an average sewage capacity of about 30 per cent. of the whole space which has been filled with coke.
3. That the sewage capacity of the coke-bed, when the bed is fed with settled sewage, fluctuates slightly, but undergoes no permanent reduction. The bed does not choke, and its purifying power undergoes steady improvement for some time.
4. That coke of suitable quality does not disintegrate during use.
5. That the "bacterial effluent" of settled sewage from the coke-beds does not undergo offensive putrefaction at all, even in summer heat, and can never become offensive. That this effluent satisfactorily supports the respiration of fish.
6. That the use of chemicals is quite unnecessary under any circumstances when the above method of treatment is adopted.

Recommendations founded on the above Conclusions.

It would appear desirable, therefore, without delay, to commence the treatment of the London sewage by the above bacterial method. The construction of the necessary works will take time and will involve expenditure, but unless it is taken in hand, all considerations tend to show that owing to the increased abstraction of water by the water companies, both at their existing intakes and at the newly constructed reservoirs for storm water at Staines, a large portion of the lower river will continuously deteriorate. This deterioration would arise from the increase in the amount of the discharge of sewage effluent and the decrease in the upper river flush. Possible trouble arising from these causes will be absolutely prevented by adopting, under proper conditions and on a large scale, the treatment which has been strikingly successful on the experimental scale. It must be remembered that the condition of the river cannot be improved by any suddenly adopted action.

If the treatment is introduced without delay and is gradually extended it may reasonably be expected that the increasing deteriora-

tion in the lower river water will first be checked and will ultimately be prevented; while the gradual development of the treatment will cause the expenditure to be spread over a period of years, and will prevent it from being unduly burdensome.

It must be remembered that the present settling channels would serve, as at present, for settling purposes, but by the altered method of working them they would also act as sludge destroyers. They should, however, undoubtedly be preceded by grit chambers. It must be further borne in mind that the expense involved in the purchase and application of chemicals would be dispensed with.

By a considerate adoption of the method, therefore, the expenditure might be distributed, and need not be large at any one time.

A fuller statement of details is supplied in subsequent sections.

Summary of Information furnished by Towns and Districts in which the Bacterial Treatment of Sewage has been employed.

A careful consideration of all the information obtained from the various centres where bacterial treatment has been tried convinces me that the process has been uniformly successful when the construction and use of the necessary plant has been reasonably and properly carried out. The only exception that appears possible to this general statement is interference which is caused by the sewage being of a very unusual character.

The following summary includes the opinions which have been expressed by all the authorities who have tried the bacterial system of sewage treatment and have reported to me on their work:—

Accrington.—The whole of the sewage is treated by the bacterial method, and the results are satisfactory.

Acton.—The experimental treatment was successful, and the effluent was approved of by the Thames Conservancy. The whole of the sewage is to be treated bacterially.

Aldershot.—"When this is done (the construction of secondary coke-beds) I think Aldershot will have every reason to be proud of the manner in which it has solved the very difficult question of how to dispose of the sewage in a satisfactory manner, and will have one of the most efficient systems in the kingdom." Annual Report of the Medical Officer of Health for 1901.

Barnsley.—The result of a temporary experiment was satisfactory.

Birmingham.—The engineer to the Birmingham, Thame and Rea

District Drainage Board states:—"The results obtained were perfectly sufficient to warrant me in saying that the sewage of the Birmingham, Thame and Rea district can be efficiently treated on prepared bacteria-beds."

Bristol.—The degree of purity of the effluent from bacteria-beds is satisfactory.

Burnley.—"We are convinced that the scheme adopted by your committee will prove an efficient one, and that the treatment of the sewage of the borough will be carried out in a more satisfactory manner and with less cost by this system (bacterial tank supplemented by land) than it could be by any other which has come under our notice." Highways and Sewage Department of the County Borough of Burnley, Report on Sewage Disposal, 23rd April, 1901, p. 20.

Bury.—"From the results obtained up to the present, the Corporation have decided to extend the works on similar lines" (*i.e.*, chemical treatment followed by subsidence and by bacteria-beds).

Chorley.—"If we had to start *de novo*, we should adopt exactly the same principle" (chemical precipitation followed by bacterial treatment).

Darwen.—"Having already proper precipitation tanks and filter (coke) beds, we do not think it advisable to change the system, as we are obtaining satisfactory results; but if a new scheme were to be laid down, many modifications would be made."

Glasgow.—The effluent from the bacterial treatment was stated on a recent visit from an officer of the council to be entirely satisfactory and non-putrescible.

Huddersfield.—"Owing to the final effluent being frequently unsatisfactory, and also to the rapid decrease of the capacity of the coarse bed, the use of this system on a large scale is not contemplated. The sewage of Huddersfield is of an exceptional character."

Hyde.—A complete scheme of sewage treatment, based upon the results of experiments of bacterial treatment, has been submitted to the Local Government Board for approval.

Keighley.—The borough engineer states: "In my opinion, bacterial treatment ought to satisfy any river authority. My council do not intend putting down a permanent installation so long as our present system of intermittent land filtration is satisfactory. There is no doubt the beds will gradually become choked, but to cleanse or renew, I think, would be cheaper than chemical treatment."

Kettering.—"The provision of filter-beds has very much improved the character of the effluent."

Leeds.—The chairman of the Leeds Sewerage Committee states that the results from a process of continuous bacteria-bed treatment "are very good indeed, giving a purification of 95 per cent."

Leicester.—A process of bacteria-bed treatment followed by final purification on land has been favourably reported upon by the borough engineer and surveyor. See report to the Highway and Sewerage and Sewage Works and Farms Committee, 1900, p. 122.

Lincoln.—The city surveyor says: "The external authorities (through whose districts the effluent stream runs), who previously had been dissatisfied with our farm and polarite-bed effluents, have expressed themselves satisfied with our bacteria-bed effluent; we therefore are completing an installation to deal with all our sewage."

Manchester.—Extract from the Annual Report of the Rivers Department for the year ending 27th March, 1901, p. 74:—"The result of the work recorded in the foregoing pages, while emphasising the necessity for care in the construction and management of sewage purification work, gives the committee every encouragement in carrying out the scheme for the bacterial treatment of Manchester sewage according to the general principles advised in the Experts' Report, 1899, and sanctioned by the Council on September 5th, 1900." The experts recommended preliminary sedimentation and screening, followed by bacteria-tank and bacteria-bed treatment.

Middleton.—The borough surveyor states:—"If of sufficient area and properly managed, they (bacteria-beds) will act satisfactorily."

Nelson.—The results obtained by experimental bacteria-beds were quite satisfactory.

Oldham.—Extract from a report entitled "The Treatment of Oldham Sewage in the year 1900," by the Medical Officer of Health, p. 3: "With the exception of a few days during the year, when the weather was very dry, the method (bacterial treatment) has been entirely successful."

Ormskirk.—The surveyor states that "the results obtained at the council's farm, after the sewage running through lagoons into settling tanks and then run on to the land and afterwards through the coke breeze filter beds, are very satisfactory and meet the requirements of the authorities."

Oswestry.—The town clerk states that they "have no doubt as to the success of the bacterial treatment. Our results are continuously satisfactory, and the effluents keep free from putrescence."

Reigate.—The result of three years' searching trial is so satisfactory as to encourage the council to sanction the outlay and adopt a scheme

Tabulation of the Results of the Chemical Examination various Coke-

I.—BARKING

TABLE IX.—*Averages of Figures relating to the Treatment of Sewage*

All quantities, except where otherwise stated,

Date.	Average daily crude sewage.		Effluent from the chemically treated and sedimented sewage as supplied to the coke-bed ("chemical" effluent).			
	Oxygen absorbed from permanganate in 4 hours at 80° F.		Oxygen absorbed from permanganate in 4 hours at 80° F.		Nitrous nitrogen.	Nitric nitrogen.
	By the crude liquid. (Total putrescible matter.)	By the clear liquid. (Dissolved putrescible matter.)	By the crude liquid. (Total putrescible matter.)	By the clear liquid. (Dissolved putrescible matter.)		
1900.						
January	11·145	5·526	6·629	4·957	0·0555	0·1430
February	11·009	5·299	6·735	5·134	0·1271	0·0907
March	11·910	6·658	7·526	6·074	0·0567	0·0936
April	12·072	6·552	7·781	6·409	0·0181	0·0234
May	12·123	6·239	6·678	5·022	Nil	Nil
June	11·441	4·940	6·018	4·355	0·0022	0·0030
July	10·848	4·663	6·136	4·203	Nil	0·0235
August	10·989	4·719	7·019	3·974	Nil	0·0970
September	11·384	5·014	6·997	5·106	Nil	Nil
October	11·382	5·247	7·377	5·942	0·0004	0·0377
November	12·056	5·766	7·417	6·175	0·0015	Nil
December	12·281	5·908	7·989	6·650	0·0276	0·0935
Average for the year..	11·646	5·543	7·015	5·344	0·0245	0·0504
1901.						
January	12·440	6·579	8·010	6·785	0·0367	0·1020
February	13·036	7·511	7·350	6·242	0·0358	0·1506
March	12·684	6·557	7·760	6·573	0·0563	0·0755
April	11·865	5·992	7·705	6·278	0·0230	0·0054
May	11·745	5·898	7·366	5·927	0·0036	0·0090
June	11·651	5·393	7·166	5·456	Nil	Nil
July	10·897	4·780	5·847	4·248	0·0081	Nil
August	10·578	4·501	5·921	3·965	Nil	Nil
September	10·577	4·516	6·337	4·336	Nil	Nil
October	11·703	5·615	7·431	5·376	0·0023	Nil
November	12·135	6·282	7·732	5·841	0·0098	0·0154
December	12·219	6·351	7·911	6·419	0·0456	0·0523
Average for the year..	11·793	5·825	7·219	5·649	0·0186	0·0346

Average percentage purification effected on the "chemical" effluent by the bacterial treatment during	1900
,, ,, ,, ,, ..	1901
,, ,, ,, ,, ..	1900-1

Average percentage purification effected on the crude sewage by the chemical and bacterial treatments combined during	1900
,, ,, ,, ,, ..	1901
,, ,, ,, ,, ..	1900-1

of the Crude Sewage, of the "Chemical" Effluent, and of the Bed Effluents.

RESULTS.

Effluent in the One-acre Coke-bed at the Northern Outfall Works.

are expressed in parts per 100,000.

Effluent from the coke-bed.				Quantity of effluent from the chemically treated and sedimented sewage which was passed on to the coke-bed per month. Gallons.	Number of times the coke-bed was filled per month.	Average quantity of effluent which was passed on to the bed each time of filling.
Oxygen absorbed from permanganate in 4 hours at 80° F.		Nitrous nitrogen.	Nitric nitrogen.			
By the crude liquid. (Total putrescible matter.)	By the clear liquid. (Dissolved putrescible matter.)					
0·890	0·723	0·0330	0·7605	23,356,361	52	449,161
0·898	0·753	0·0362	1·0868	18,400,442	46	400,010
0·998	0·866	0·0352	1·0071	18,354,936	52	352,980
1·086	0·934	0·0439	1·2021	14,391,847	42	342,663
0·972	0·840	0·0444	0·9490	17,015,411	52	327,219
0·939	0·760	0·0542	0·9053	13,792,523	43	320,756
0·999	0·792	0·0501	0·6007	16,002,669	50	320,053
1·010	0·808	0·0502	0·8458	12,168,147	38	320,214
1·029	0·840	0·0991	1·2353	15,823,348	46	343,986
1·019	0·848	0·0691	1·3078	18,044,051	52	347,001
1·131	0·979	0·0743	1·3023	16,025,918	46	348,390
1·083	0·942	0·0608	1·3347	15,630,440	44	355,237
1·003	0·840	0·0541	1·0429	199,006,093	563	353,474
1·023	0·919	0·0626	1·1776	18,413,046	52	354,097
1·161	1·055	0·0872	1·3095	16,121,827	46	350,474
1·126	1·039	0·0701	1·3298	16,924,070	50	338,481
1·123	1·011	0·1004	1·1117	15,481,724	46	336,559
1·158	1·029	0·1176	0·6283	16,558,407	50	331,168
1·161	1·010	0·1016	0·7862	16,012,550	48	333,595
1·021	0·856	0·0718	0·7253	16,889,950	51	331,175
1·009	0·845	0·0710	0·6797	15,972,684	48	332,764
0·914	0·790	0·0637	1·0986	11,751,012	35	335,743
0·910	0·790	0·0685	0·6663	14,976,516	45	332,811
0·952	0·821	0·0525	0·8259	16,405,221	50	328,104
0·973	0·861	0·0741	1·1641	14,612,640	44	332,105
1·045	0·920	0·0782	0·9513	190,119,647	565	336,495

85·7	84·3
85·5	83·7
85·6	84·0
91·3	84·9
91·1	84·2
91·2	84·5

for treating the whole of the sewage of the borough on the lines adopted by the experimental plant."

Salford.—The borough engineer states that "we can fully depend upon the bacteria-beds to give a satisfactory effluent, even when working night and day, almost without intermission." Permanent beds to treat the whole of the sewage are being constructed.

Sheffield.—"The degree of purification obtained has been uniformly satisfactory. The loss of capacity of the beds continues, and experiments are being conducted with the object of reducing this as much as possible. Permanent works on bacterial principles are contemplated, but working details cannot be decided upon until further experiments are completed."

Southport.—The Medical Officer of Health says that the "bacteria-beds are only small experimental ones. . . . They have, however, worked entirely to our satisfaction so far as we have tested them, and they have always produced a clear and non-putrescible effluent."

Walsall.—The borough surveyor states that in the Bloxwich district first-class results are being obtained in the bacterial treatment of the sewage.

Wolverhampton.—The town clerk states that the results of the coke-bed treatment are good, but that a permanent installation is doubtful owing to the presence in the sewage of iron salts in large quantities.

York.—In a report to the sewage committee, dated October, 1901, the city engineer states (on p. 41), with respect to an experimental plant consisting of an open septic tank and continuous treatment in coke-beds, that the results were excellent and the filtrate was non-putrescible. That "the system is adaptable for larger quantities per square yard than any other experiment," and that there is no loss of liquid capacity in the coke-bed.

Short Summary of the Evidence given before the Royal Commission on Sewage Disposal.

It has been suggested that the results arrived at by the Royal Commission on sewage disposal would be of great value to the Main Drainage Committee of the Council. The Commission have now published their minutes of evidence, and a careful perusal of the evidence given by the independent experts, including engineers, bacteriologists and chemists, shows that they are in general agreement in maintaining that the only known method of producing a satisfactory sewage effluent on a large scale is by the adoption of one or other of the various systems of bacterial treatment.

The bacteriologists gave evidence to the effect that the purification of sewage was a combined anaërobic and aërobic process, and that the best results were obtained by a more or less perfect anaërobic treatment, followed by an aërobic treatment. The evidence in support of this view tendered by Professor Marshall Ward and by Dr. Sims Woodhead, is mainly based on theoretical grounds, and will be found to be of great value and interest.

On the other hand, Dr. Adeney, Colonel Ducat and others, claim that their processes are entirely aërobic in their character. In face of the above evidence this contention appears very doubtful, and it is more likely that the one treatment succeeds in combining the two processes.

The great majority of the witnesses agree that crude sewage cannot be successfully treated by contact beds alone, since, although the results are good and a non-putrescible effluent is produced, the liquid capacity of the beds diminishes so rapidly that they soon become useless.

In order to prevent this choking of the beds and to maintain their liquid capacity, almost all of the schemes described include a preliminary process of sedimentation which is in most cases also rendered an anaërobic or so-called "septic" process. Its main objects are to free the sewage from mineral suspended solids and to cause the complex suspended organic solids to pass into solution and to become simplified in nature. In the subsequent aërobic process, usually carried out in coke-beds, opinion is divided as to the respective merits of a continuous and of an intermittent supply. It must be said that those who support the continuous treatment make out a good case so far as the results obtained are concerned. The continuous system seems to produce nitrates in larger amount than does the intermittent system, but at the same time the effluent is by no means as free from suspended solids which appear to be washed through the bed. Some special method of distribution of the liquid to the bed is required by the continuous treatment, and this is not only a cause of additional expenditure, but also of additional trouble in maintenance as compared with the intermittent system of supply.

It is generally agreed that the liquid capacity of a new bed falls rapidly when it is first started, but it is maintained that this decrease soon ceases, and that a permanent capacity can be insured by an intelligent working of the bed. The extreme capacity values vary from 20 to 33 per cent. of the whole space represented by the bed when full—including both coke and liquid. An average of about 30 per cent. would represent the average permanent capacity of a working bed.

Three fillings of the beds per day were advocated by most of the

witnesses, and the quantity of sewage per day dealt with by an acre of bed, three feet in depth, was placed at not more than 800,000 gallons. This is undoubtedly understating the capabilities of the bacterial system. Deep beds have given quite as good purifying results as shallow beds.

The quantity of sludge which disappears by anaërobic action in the settling or "septic" tank is variously estimated at from 20 to 60 per cent. of the whole amount deposited in the tank. It is curious to note that Mr. Whittaker claims that no sludge disappears in his septic tank, though he admits that large quantities of gas are found. (Questions 5742—65.) In cross-examination on this matter, he can hardly be said to have proved his statement.

It was generally admitted that a septic tank effluent is capable of being rendered non-putrescible by one contact in an aërobic bed.

Professor Letts, in his evidence with reference to the purification of Belfast sewage, stated that salt prevented the formation of nitrates. This perhaps accounts for the low proportion of nitrates found in the effluents from the Crossness beds, as compared with that found in the effluent from the Barking beds, since Crossness sewage contains an abnormal quantity of salt.

Dr. Adeney's evidence will be found to have a bearing on the present and probable future condition of the river Thames.

Briefly, it may be said that although the experts differed in small matters of detail, they agreed in the broad principles of sewage purification by bacterial means, and their evidence is a strong confirmation of the results obtained by the experimental work carried out at the Council's outfalls.

Table X.—*Particulars as to the Disappearance of Sludge in the Settling-tank at the Southern Outfall Works. (Series III.)*

	During the period from Nov. 1st, 1900, to Mar. 28th, 1901.	During the period from Mar. 29th, 1901, to Oct. 5th, 1901.	During the whole period from Nov. 1st, 1900, to Oct. 5th, 1901.
1. *Crude Sewage.*	2.	3.	4.
Quantity of crude sewage supplied to settling tank..gallons	2,768,160	2,427,250	5,195,410
Average amount of suspended solids in the crude sewage ..... parts per 100,000	28·1	25·3	..
Average amount of suspended solids in the crude sewage ..... grains per gallon	19·7	17·7	..
Weight of suspended solids supplied to the tank ..... Mineral constituents of solids..lbs.	3,241	2,553	5,794
Weight of suspended solids supplied to the tank ..... Organic constituents of solids..lbs.	4,549	3,584	8,133
Weight of suspended solids supplied to the tank ..... Total solids .....lbs.	7,790	6,137	13,927
Settled Sewage.			
Quantity of settled sewage which passed out of the settling tank .....gallons	2,765,548	2,427,593	5,193,142
Average amount of suspended solids in the settled sewage ..... parts per 100,000	12·5	14·3	..
Average amount of suspended solids in the settled sewage ..... grains per gallon	8·8	10·0	..
Weight of suspended solids which passed out of the tank .... Mineral constituents of solids..lbs.	1,406	1,418	2,824
Weight of suspended solids which passed out of the tank .... Organic constituents of solids..lbs.	2,031	2,050	4,081
Weight of suspended solids which passed out of the tank .... Total solids .....lbs.	3,437	3,468	6,905
Sludge.			
Actual quantity of sludge found in the tank .....gallons	2,612	2,269	2,269
Average amount of suspended solids in the sludge found in the tank .....percentage	..	..	16·4
Weight of suspended solids in the sludge found in the tank.. Mineral constituents of solids..lbs.	..	..	2,808
Weight of suspended solids in the sludge found in the tank.. Organic constituents of solids..lbs.	..	..	1,322
Weight of suspended solids in the sludge found in the tank.. Total solids .....lbs.	3,240	..	4,130
Calculated quantity of sludge left in the tank	..	..	..
Average amount of suspended solids removed from the sewage and left in the tank ..... parts per 100,000	15·6	11·0	..
Average amount of suspended solids removed from the sewage and left in the tank ..... grains per gallon	10·9	7·7	..
Weight of suspended solids in the sludge left in the tank .... Mineral constituents of solids..lbs.	1,835	1,135	2,970
Weight of suspended solids in the sludge left in the tank .... Organic constituents of solids..lbs.	2,518	1,534	4,052
Weight of suspended solids in the sludge left in the tank .... Total solids .....lbs.	4,353	2,669	7,022
Quantity of sludge (organic matter only) which disappeared by the septic action in the tank .....lbs.	1,113	..	2,892
Percentage quantity of sludge which disappeared, calculated on total solids	25·6	..	41·2
Percentage quantity of sludge which disappeared, calculated on organic constituents	..	..	71·4

"The usual method of working the septic tank was to allow a unit volume of sewage about six hours to pass through the tank. This was equal to the average time which a unit volume of sewage takes to pass through the large settling channels in the chemical and sedimentation process."

CHAPTER V.

SUTTON EXPERIMENTS.

Experiments with Sewage collected on the "Separate System," excluding Rainfall.

At my suggestion, as a result of the original experiments at the Barking Outfall, as described in Chapter IV., similar experiments were commenced at the works of the Sutton (Surrey) Urban District Council in 1894. The works were at that time under the direction of Mr. A. D. Greatorex, Assoc. M.I.C.E., Surveyor to the Board.

The filters employed were seven in number, as follows:—

		Square feet each.
Two proprietary, 35 ft. by 20 ft.	area	700
Two coke breeze ,, ,,	,,	700
Two sand ,, ,,	,,	700
		4200
One burnt ballast { 142 ft. / 120 ft. } by 34 ft.	,,	4454
Total area		8654

The filters were constructed as follows:—

Proprietary.

Top, 6½ in., medium sand.
3 in., pea gravel.
10½ in., proprietary article mixed with sand.
5 in., extra coarse sand.
4 in., pea gravel.
Bottom, 5 in., coarse shingle round the pipes.

Construction of Filters—*continued.*

Coke Breeze.

Top, 8 in., medium sand.
12 in., coke breeze.
5 in., extra coarse sand.
4 in., pea gravel.
Bottom, 5 in., coarse shingle.

Sand.

Top, 8 in., medium sand.
12 in., coarse sand.
5 in., extra coarse sand.
4 in., pea gravel.
Bottom, 5 in., coarse shingle.

Burnt Ballast.

Top, 4 in., soil (afterwards removed).
6 in., fine ashes.
Bottom, 18 in., burnt ballast.

120,000 gallons of effluent water were passed through the filters per day, working nine hours. The six small filters were worked one day, and the large the next day, thus allowing alternate days of rest.

In his report of the 18th July, 1894, Dr. Jacob, the then Medical Officer of Health for the Sutton District, stated that the effluents from the various filters were quite fit to be discharged into the brook without further treatment.

In view of this result, it was thought that under proper conditions there was no reason why the whole of the suspended matters in the sewage should not be amenable to similar treatment, and I therefore ventured to recommend the experiment of filling a tank with coarse burnt ballast and running the crude sewage upon it. This suggestion was adopted, and on November 21st, 1896, the "bacteria tank" was filled for the first time, and kept constantly at work for five years, when it was put out of action in consequence of the rearrangement of the works. At the end of that time it was still in good working order. The results of the first two and a half months' work were embodied in a report made by

me to the Sewage Disposal Committee of the Sutton Urban District Council on February 11th, 1897, from which the following is extracted :—

The tank, charged with burnt ballast, was prepared for the reception of the sewage by inoculating it with bacteria; my former experiments having shown that such preliminary treatment contributed materially to better work.

The tank was first filled on the 21st November with the raw sewage (untreated with chemicals), which had been strained through a screen to intercept the grosser particles.

The total quantity of sewage treated during the period of seventy-six (76) days was 2,216,000 gallons, equal to an average of 29,165 gallons per day, or 773,000 gallons per acre per day, rest period included.

The results obtained have been of the most satisfactory character. The quantity of oxygen required to oxidise the organic matter in solution on the raw sewage was, on an average, 5·40 grains per gallon, which was reduced by the bacteria tank to 1·83 grains, or a reduction of 66 per cent. The further treatment of this effluent by the coke-breeze and other filter beds reduced this required oxygen to 0·72 grain per gallon, or a total reduction of the oxidisable matter by 86·5 per cent.

In like manner the solid matters held in suspension in the sewage were reduced by the bacteria tank by 95 per cent., and by the combined system by 99·6 per cent.

With the exception of the few days when the filter was overworked the sewage odour was completely removed, there being in the effluents only an earthy odour similar to that of fresh-turned garden soil.

It appears from these results that a bacteria tank or tanks of an area of half-an-acre will be sufficient for the complete disposal of the sludge by this system, without any expense for labour other than that necessary for turning on the valves and raking over or digging with a fork the surface of the ballast from time to time as may be required to break up the surface coating of fibrous matter. Up to the present time this has been found to be necessary on only two occasions.

It may be remarked that the quantity of suspended solid matters in the sewage which has been disposed of by the bacteria during the seventy-six days they have been at work is equal to 77 tons of sludge, as the average sewage contained 54·5 grains of suspended matter per gallon. The fact that this quantity has disappeared without cost or nuisance is striking evidence of the capabilities of the process.

The importance of this method in the case of new sewage works is evident, as the whole of the elaborate machinery for chemical treatment, sludge pressing, farming operations, &c., will be avoided; and where such farms exist, as in the case of Sutton, these may be utilised for the purpose of a recreation ground, and so settle a question of no little importance; as, by the utilisation of the life processes of bacteria, the effluent from the double set of beds is more fitted for discharge into the brook than if it were allowed to run over the land, which may then be used for other purposes.

The final filtrates were free from all objectionable odour, and remained perfectly sweet on keeping in either open or closed vessels.

The analyses disclosed some very instructive features in regard to the degree of nitrification when the filters were being overtaxed, some of them having been purposely worked up to a rate of nearly three millions of gallons per acre per day, with the result that the bacterial action was evidently checked as shown by the decrease in the production of nitrates, and an increase in the normal quantity of organic constituents in the effluent. As the result of careful watching, however, no permanent harm was done, as the filters were immediately restored to their usual condition, when they proceeded to give good results.

Many suggestions have been made, both in England and America, to effect the purification of sewage on a working

scale, and in sufficient quantity, by aiding the oxidising bacteria by blowing streams of air through the filter bed. The effect of this is to save on one hand and to expend on the other. In the case of the Sutton works no air enters the filter other than that caused by the natural process following the drawing off of the water, when of necessity the pores of the ballast must be re-charged with a supply of the revivifying oxygen.

Another collateral advantage of the extension of the system will be that the sewage brought to the lower part of the works by the low-level sewer can be treated direct on beds provided at that level, and thus the expense of pumping the sewage up to the high-level tanks will be obviated.

The first edition of the present work contained the following paragraph, which time has completely justified:—

> The combination of mechanical skill with the bacteriological and chemical sciences is thus rapidly working towards an advance in the progress of sanitation quite in keeping with the signs of the times. It is not wise to be too sanguine; but the outlook is such that it may well be hoped that in a few years all the old ideas of precipitation, farming, &c., will be extinct, and sewage works will have nothing more offensive or objectionable in character about them than has a market garden.

In March, 1899, after two and a half years' working, it was found that the bacterial treatment, which in the interval had been considerably extended, reduced the matters in suspension from 67·2 grains per gallon to 0·0 grain; the oxygen absorbed from 3·517 grains per gallon to 0·578 grain, and the albuminoid ammonia from 0·380 to 0·059 grain; whilst nitrification has taken place to the extent of 2·123 grains of nitrogen per gallon.

The percentage purification, therefore, being—

Matters in suspension - - -	100
Albuminoid ammonia - - -	84
Oxygen absorbed in four hours -	89

The following tables of the working of the coarse and fine-grained beds, or, as they are often termed, the "primary" and "secondary" beds, were prepared by Mr. C. Chambers Smith, the Surveyor of the Sutton Urban District Council, after the original bed had been in work, as stated above, for two and a half years :—

TABL

Coarse Grain

Table of Capacities of Filters,

No. of Filter.	DATE.	Area.	Depth.	Total capacity of Filters.	Average quantity of Sewage treated at each Charge.	Percentage of Sewage at each charge to total Capacity.	Total Number of Charges.	Number of Days.
		Sup yds	Ft. Ins.	Cub. ft.	Gallons.			
1	Nov. 21st, 1896, to Aug. 21st, 1897.	186½	3 6	5,871	13,500	36·8	540	274
	Aug. 22nd, 1897, to Mar. 31st, 1898.	186½	5 3	8,807	13,168	24	505	222
	April 1st, 1898, to Feb. 2nd, 1899.	186½	5 3	8,807	8,230	15	721	308
	Feb. 3rd, 1899, to Mar. 31st, 1899.	186½	3 7½	6,081	7,198	19	159	57
	Totals and averages....	—	—	—	—	23·7	1,925	861
2	June 3rd, 1897, to March 31st, 1898.	186½	5 3	8,807	10,974	20	630	302
	April 1st, 1898, to March 31st, 1899.	186½	5 3	8,807	8,779	16	826	365
	Totals and averages....	—	—	—	—	18	1,456	667
3	July 23rd, 1897, to Mar. 31st, 1898.	186½	5 3	8,807	13,717	25	552	252
	April 1st, 1898, to Feb. 6th, 1899.	186½	5 3	8,807	10,974	20	675	312
	Feb. 7th, 1899, to Mar. 31st, 1899.	186½	4 1½	6,919	10,345	24	138	53
	Totals and averages....	—	—	—	—	23	1,365	617
4	April 30th, 1898, to Mar. 31st, 1899.	186½	5 3	8,807	14,862	27	895	336
	Totals and averages....	—	—	—	—	22·9	5,641	2,481

XI.

Bacteria Filters.

and Quantity of Sewage Treated.

Average Number of Charges per day.	Number of Hours at		Total quantity of Sewage treated.	Average quantity of Sewage treated per Day.	Average quantity of Sewage treated per cub. yd. per day.	Tons of Sludge of 90 p.c. moisture destroyed on the basis of 55 grains per Gallon as per Analyses.	REMARKS.
	Work.	Rest.					
			Gallons.	Gallons.	Gallons.		
1·97	2,299	4,262	7,290,000	26,606	122·3	255	Filtering material composed of burnt ballast exceeding ¾-in. gauge.
2·27	2,915	2,413	6,649,840	29,954	91·8	233	Increased in depth, Aug. 22nd, 1897.
2·34	2,520	4,872	5,933,830	19,266	59·0	208	
2·79	480	888	1,144,482	20,080	89·1	40	Reduced in depth, Feb. 2nd, 1899.
2·23	8,214	12,435	21,018,152	24,411	90·5	736	
2·08	2,898	4,351	6,913,620	22,893	70·2	242	Filtering material of burnt ballast in layers, 2 ft. of fine material being placed in bottom of filter.
2·26	2,887	5,873	7,251,454	19,867	60·9	254	
2·18	5,785	10,224	14,165,074	21,237	65·1	496	
2·19	3,184	2,864	7,571,784	30,047	92·1	265	Filtering material similar to No. 1.
2·16	2,449	5,039	7,407,450	23,741	72·8	259	
2·60	468	804	1,427,610	26,936	105·1	50	Reduced in depth, Feb. 6th, 1899.
2·21	6,101	8,707	16,406,844	26,591	90·0	574	
2·66	3,408	4,656	13,301,490	39,588	121·3	466	Filtering material similar to No. 1.
2·27	23,508	36,022	64,891,560	111,827	91·7	2272	

Table XII.—Fine Grain Bacteria Filters.

Table of Capacity and other details of Filters.

No. of filter.	MATERIALS.	Area.	Depth.	Total capacity of filter.	Average quantity of effluent treated at each charge.	Percentage of effluent at each charge to total capacity of filter.	Average quantity of effluent treated per cubic yard of filtering material per day, charging three times.
		Sup. yds.	Ft. Ins.	Cub. ft.	Galls.		Galls.
1	24 inches burnt ballast ..	77⅞	2 10	1,983	3,494	28	142·8
	5 ,, pea gravel						
	5 ,, coarse gravel						
2	3 inches pea gravel.....	77⅞	2 1½	1,487	2,403	26	131·1
	10½ ,, polanite & sand						
	4 ,, extra coarse						
	3 ,, pea gravel						
	5 ,, coarse shingle						
3	8 inches ⅝ coke breeze	77⅞	2 10½	2,012	4,369	35	175·9
	12½ ,, over ⅝ ,,						
	5 ,, extra coarse sand						
	4 ,, pea gravel						
	5 ,, coarse gravel						
4	8 inches ⅝ coke breeze ..	77⅞	2 11	2,042	4,587	36	182·0
	13 ,, over ⅝ ,,						
	5 ,, extra coarse sand						
	4 ,, pea gravel						
	5 ,, coarse gravel						
5	20 inches sand	77⅞	2 11	2,042	3,712	29	147·3
	5 ,, coarse sand						
	5 ,, pea gravel						
	5 ,, coarse shingle						
6	19½ inches sand.....	77⅞	2 10½	2,012	3,819	30	153·8
	5 ,, coarse sand						
	5 ,, pea gravel						
	5 ,, coarse shingle						
7	10 inches coke breeze passed through ⅜ mesh	465⅞	2 8	11,179	22,278	32	161·4
	22 inches burnt ballast rejected by ⅜ mesh						
8	4 inches coke breeze	684⅓	2 9	16,940	33,200	32	158·7
	29 ,, burnt ballast						
	Totals and averages			39,697	77,862	31·38	158·8

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In January, 1900, in consequence of the increased volume of sewage arriving at the Sutton works, it became necessary to provide an extension of the plant, and the surveyor, Mr. C. Chambers Smith, advised the construction of additional bacteria beds, at a cost of £1,740, instead of the purchase of 27·5 acres of land for irrigation at a cost of £7,700. This fact in itself showed the advantage in cost alone of the new system.

With regard to the working expenses, Mr. Chambers Smith expressed the opinion that the policy of the Council in constructing these filters had been a sound one, as evidenced by the fact that the cost of working the farm prior to their introduction, viz., for the year ending 1895, with 69,880,000 gallons of sewage, was £1,089 19*s.* 3*d.*; whilst the cost for the year ending March 31st, 1899, with 157,164,000 gallons was £621 1*s.* 11*d.*, the average cost of treating one million gallons in 1895 being £15 11*s.* 1*d.*, whilst in 1898-9 it was £3 19*s.* 0*d.* (including pumping, &c.). The net result, therefore, was that the town was saved an annual charge of £1,190 by the introduction of the bacterial system.

In order to ascertain the possibility of treating large quantities of storm water brought to the outfalls by a "separate system" of sewers, experiments were made with the beds at Sutton by allowing them to fill quite full with the storm water and then opening the outlet valve just sufficient to enable the water to escape as fast as it ran on to the beds, this operation being known as "streaming." Table XIII. shows the results, which were entirely satisfactory. The beds on being put to work again with the ordinary crude sewage showed equally good results as before the streaming, the action of nitrification having been unimpaired. Similar experiments were carried out with the beds at the Worcester Park works, and like results obtained.

CHAPTER VI.

THE SEPTIC TANK AND OTHER SYSTEMS.

In view of the attention called to the success of the bacterial treatment of sewage by the Massachusetts experiments and those at the Barking Creek Outfall, the question was speedily taken up, with the result that Mr. Donald Cameron, then City Engineer to the Corporation of Exeter, undertook a series of experiments with a view to bringing about the destruction of the solid organic matter in the sewage by a preliminary process of anaërobic treatment in a covered tank, which for distinction was termed a "septic tank," and under which title it is now generally known. About the same time, Mr. Scott-Moncrieff carried out a series of experiments at his residence at Ashtead, in Surrey, where he employed a cesspool, covered with a gravel filtering bed. The cesspool was kept filled with water, so that when a fresh charge of sewage was let into it the overflow escaped through the gravel bed. Thus the solid matters were retained, but the escaping effluent, although free from solids, was yet in a far from pure condition. Mr. Cameron adopted the system of the two-hour contact beds in use at Barking for the purification of the effluent from the septic tank, and caused these to work alternately by a system of valves worked by the overflow from a recently filled bed falling into a tilting bucket which, when full, dropped and actuated the necessary valves to divert the flow on to another bed which had been resting empty, and at the same time opened the outlet valve from a third bed

which had been resting full and was ready to discharge its contents.

Mr. Scott-Moncrieff subsequently arranged that the effluent from the tank should flow on to a series of trays consisting of nine wooden boxes with perforated bottoms, each 2 ft. long by 7 in. wide and 7 in. deep, an allowance of ½ in. along each side being made, so that each tray had an area of 1 square foot. The trays were placed one above the other, and were each filled with coke which had passed through a 1 in. ring. Over the uppermost box were fixed two small tilting V-shaped tipping troughs, which alternately discharged their contents when the liquid reached the level that upset their equilibrium, as they hung upon small trunnions fixed at the proper point to effect this movement, and working upon supports fixed to the ends of the highest box. The boxes were separated by an air space of two inches, which thus provided means for the effectual aëration of the effluent and filtering medium. It was thus also practicable to take samples of the effluent as it came from each tray, and so to judge of the progress of the purification in detail.

The following Table XIV., from Mr. Scott-Moncrieff's paper on "High Nitrification in Sewage Treatment," read at the Sanitary Institute Congress at Southampton in 1899, shows the results of analyses of samples taken by Dr. Rideal from each of the nine trays in February, 1898:—

Table XIV., showing successive stages of Mineralization by Nitrifying Organisms. Ashtead Experiments, February, 1898.

	Description of Samples.	A Chlorine.	B Free NH_3	C = N.	D Albuminoid NH_3	E = N.	F Oxygen consumed.	G O_2 consumed minus O_2 required by Nitrous Nitrogen.	H Nitrous Nitrogen.	I = Oxygen required.	J Nitric Nitrogen.	K = Useful Oxyg'n. N_2O_5 to N_2O.	L Total Oxidised Nitrogen.	M Available Oxygen useful, O_2. Nitrate = O_5 consumed.	N Total Unoxidised N. (Kjeldahl).	O Total Organic Nitrogen.	P Total Inorganic Nitrogen.	Q Total Nitrogen of all kinds.
	Effluent from Cultivation Tank, taken 3 and 5 p.m.	9·0	12·5	10·30	1·50	1·23	9·843	9·843	Nil.	—	0·12	0·274	0·12	− 9·57	12·35	2·05	10·42	12·47
Colonies of Aerobic Nitrifying Organisms.	1. Effluent from First Tray	9·0	10·5	8·65	1·25	1·03	6·694	5·56	0·99	1·13	0·096	0·219	1·036	− 6·47	11·5	2·85	9·74	12·59
	2. Effluent from Second Tray	8·5	9·0	7·42	1·00	0·82	5·773	4·74	0·90	1·03	0·48	1·09	1·38	− 4·66	11·10	3·68	8·80	12·48
	3. Effluent from Third Tray	8·5	5·0	4·12	0·60	0·49	4·493	3·60	0·78	0·59	1·87	4·27	2·65	− 0·22	6·60	2·48	6·77	9·25
	4. Effluent from Fourth Tray	8·0	4·0	3·3	0·35	0·29	1·728	0·98	0·66	0·75	2·76	6·30	3·42	+ 4·58	5·15	1·85	6·72	8·57
	5. Effluent from Fifth Tray	7·75	1·5	1·24	0·15	0·12	1·28	0·73	0·48	0·55	4·68	10·70	5·16	+ 9·42	1·75	0·51	6·40	6·91
	6. Effluent from Sixth Tray	8·0	1·75	1·44	0·35	0·29	1·497	0·92	0·51	0·58	4·416	10·10	4·926	+ 8·61	2·25	0·81	6·37	7·18
	7. Effluent from Seventh Tray	7·5	0·35	0·29	0·30	0·25	0·755	0·755	Nil.	—	6·6	15·08	6·6	+ 14·33	0·85	0·56	6·89	7·45
	8. Effluent from Eighth Tray	7·5	0·20	0·165	0·65	0·53	0·397	0·397	Nil.	—	7·32	16·73	7·32	+ 16·34	1·03	0·865	7·48	8·35
	9. Effluent from Ninth Tray	7·5	0·25	0·206	0·60	0·49	0·589	0·589	Slight trace	—	9·0	20·0	9·0	+ 20·1	0·60	0·394	9·21	9·60

It will be seen from this table that a remarkably high degree of nitrification is attained, the loss of nitrogen during the process being only about 25 per cent. and the final effluent containing 9·0 parts of nitric nitrogen per 100,000.

The latest views of Mr. Scott-Moncrieff were given by him in an address to the Association of Sewage Works Managers on the 28th March, 1903, from which the following observations are abstracted :—

After long consideration, I came to the conclusion that at any rate where new filters were being put down, the circular form was the best, as it presented a good many obvious advantages—among others, that the largest area was included in any given length of masonry—and accordingly I designed a large distributor, capable of dealing with 250,000 gallons per twenty-four hours; and two of these are now at work—one at Birmingham, and one at Hanley, in Staffordshire. The peculiar feature of this form of distributor is that the different areas to be covered at each point of the revolving radius are provided for by means of two parallel channels running from end to end of the arm, one of which acts as a continuous duct, communicating at short intervals through the intervening dividing plate with the other channel, which is divided up into short sections, each having a different sized opening into the main channel corresponding with the quantity of liquid to be delivered at each point in the radius, further provision for accurate distribution being made by means of movable weirs so adjusted as to provide accurately for equal feeding over equal areas. By this means the greatest exactness can be secured in the flow of the liquid at every point, and this is verified by the simple device of laying a shallow box exactly 1ft. square on any part of the surface of the filter, which receives just one pint of liquid as the distributor passes over it.

It is only right that I should lay before you, as concisely as I can, first, what I believe to be the complete means of arriving at the most satisfactory result; and, secondly, the realisations of these requirements that have already been put into practice on a large scale. Taking these in their order, I would say that the sewage should first be taken in a long, narrow carrier, from which it escapes at right angles and at intervals about one yard apart through regulated openings into a shallow grit chamber of the necessary dimensions to allow of the deposition of solid mineral matter in suspension. From this grit tank it should be passed either through restricting channels provided with gratings and upward through large stones, an arrange-

ment known as a "cultivation tank," or through ordinary tanks, either open or covered.

After having been in the grit chamber about five hours, and the anaërobic tank about two hours, the raw incoming sewage should be diverted to a second set of grit chambers and tanks, and the liquid which has been longest in the anaërobic tank should then be circulated so as to pass again through the first grit chamber to complete the hydrolysis of the suspended organic matter which will otherwise appear as sludge. This circulation of the liquid should go on until the organic sludge is reduced to a minimum. The liquid from the anaërobic tank after having rested long enough to allow of complete liquefaction should be passed into a distributing machine and distributed over a bed of hard filtering material gauged to pass a ¾in. mesh and rejected by a ¼in. mesh of a sufficient depth, and the feeding of the effluent should be so arranged as to allow of a sufficient interval between each feeding to prevent formation of gelatinous growths; at the same time a sufficient quantity of air should be aspirated through the filter bed to remove the carbonic gas, and so as to provide for oxidising the ammonia to nitric nitrogen. Finally, the effluent should be used upon land, and for growing fruit and vegetables under glass.

Colonel Ducat proposed to employ aërobic action entirely, and with this view constructed a filter with open sides, formed by using agricultural drain-pipes cemented side by side, this wall being strengthened by brick piers at intervals. As the filtering medium was placed in the filter, proceeding from fine material at the bottom to coarse material at the top, other similar drain-pipes were laid at intervals from the walls into the middle of the bed, the design being to make an open way for the atmosphere into all parts of the bed. The sewage was allowed to drop from troughs laid horizontally over the surface of the bed, and to slowly percolate through the successive layers of filtering material until it escaped from the open bottom of the bed, which was properly supported for that purpose on a concrete floor.

Mr. Stoddart, of Bristol, modified this plan by doing away with the built-up open pipe walls, and constructed a filter merely of a heap of coarse rubble, clinker, ballast, coke or

other material placed upon a concrete or other impervious floor, laid with sufficient fall to cause any liquid that reaches it to flow towards the nearest external surface. The nature and composition of the filtering medium is immaterial so long as it is insoluble in water and not too friable, but Mr. Stoddart recommends that it should be as irregular in fracture as possible, and that the sizes of the particles should in no case be less than 3 inches in diameter.

I am indebted to Mr. Stoddart for the following account of his experiments and methods now employed:—

The intermittent filter of the Royal Commission of 1868 was, as has already been said, an attempt to reproduce in a more intense and manageable form the changes which sewage and similar matters undergo when spread upon the soil, and a consideration of what is actually observed in such cases should furnish the means of judging correctly how far this attempt was successful.

If an inspection be made of a leaky cesspit or defective drain it will be found that the soil immediately adjacent is blackened, sodden and foul; but this condition is strictly limited, and that at a very short distance, depending on the amount of leakage and porosity of the soil, these appearances will vanish. Water collected beyond this point, though obviously oozing from the cesspit which it may have left but a few minutes previously, will be sweet and fresh to the smell and taste. Examined chemically it will be found that the ammonia and organic matter characteristic of the foul exudation have been displaced by oxidised products, nitrates, sulphates, and carbonates. This is exactly the change aimed at and achieved by the Royal Commissioners, but THERE IS NO INTERMITTENCE. An inspection of the soil at the point at which the purification begins to be obvious will reveal the fact that this spot is also that at which the ratio of sewage to soil is small enough to enable the latter to remain permanently charged with air. It is clear that in attributing prime importance to oxidation as the essential feature of sewage purification the Commissioners were absolutely correct, but in concluding that alternately dosing the filter with sewage and air was the only practical means of effecting this change they were as completely wrong. So far from being a *sine quâ non*, "intermittency of application" is but a series of compensating errors of surfeiting and starvation.

A consideration of these facts primarily as regards their bearing on the contamination of drinking waters, led the author to construct a

filter representing as nearly as possible the exact conditions existing in soil polluted by a leaky drain. That is to say, a constant trickle of sewage was maintained over a coarse medium (chalk), the interstices of which were not allowed to become water-logged but remained open and in communication with the external air.*

This apparatus, the first continuous sewage filter on record, was described in 1893, and shown at work at the Bristol meeting of the British Medical Association in 1894; in considering its effect it is necessary to bear in mind that nitrification, or the conversion of the nitrogen contained in sewage into nitric acid, is only a part of the whole question of the oxidation of sewage; but that as it has undergone more complete investigation, and results in products capable of more definite estimation than is the case with some concurrent changes, a determination of the stage to which nitrification has been advanced serves well as an indication of the progress of oxidation.

Now by means of the experimental filter referred to, several interesting points were elucidated, of which the following are the most important in the present connection:—

1. The quantity of nitrogen that could be oxidised under the best conditions was shown to be enormously in excess of anything previously demonstrated.

   Using a solution of ammonium sulphate containing 10 grains of nitrogen per gallon, fully 2,000 gallons was oxidised per square yard of surface in twenty-four hours with almost theoretical completeness.

   Sewage treated in the same way was completely nitrified at the rate of 200 gallons, and was sufficiently purified to comply with the usual standards at the rate of 1,000 gallons on the same area.

2. In order to bring about and maintain this pitch of efficiency it was absolutely essential that air should be always present in unbroken continuity from the top to the bottom of the filter. Even if, for instance, the outlet of the filter became occluded by accumulation of filtrate, the oxidation speedily became imperfect; and the same thing resulted if a continuous horizontal layer of liquid formed at any point in the filter.

   This condition was fulfilled without difficulty by:—

   (a) Feeding the filter by means of a drop arrangement.

   (b) Using so coarse a medium that even when thoroughly wetted the interstices were large enough to prevent the films of liquid from coalescing.

   (c) Thoroughly draining the base of the filter.

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* Stoddart—*Practitioner*, li. (1893) 391-5; *Analyst*, xviii. 293; xix. 39.

3. When the filter was brought to the highest degree of efficiency a single flushing with liquid, and especially with sewage, almost completely abolished its oxidising power, which was only slowly regained, and did not resume its former exalted action for several days. This result is in accordance with the observations of Warrington, Frankland, and others to the effect that the nitrifying bacilli work very sluggishly when immersed in liquid, and that their action is inhibited by any great quantity of organic matter.
4. On stopping the flow of real or artificial sewage, the power of nitrification diminished only very slowly, and was not entirely lost after an interval of two years; on the other hand, it could speedily be re-established in full vigour by renewing the flow of sewage.
5. The amount of nitrogen oxidised was directly proportionate to the depth of the filter, so that the area could be diminished if the depth were increased so long as the application of sewage was not so copious as to cause it to coalesce into a continuous layer. This limit depends upon the grade of the medium; with particles ranging from two to three inches in diameter, 10,000 gallons per square yard per day produce no indications of water-logging.

It was pointed out that the exceptional activity of this filter was "obviously due to the more regular and continuous flow combined with perfect aëration." *

A filter, then, arranged on this plan appears to present ideal conditions for sewage oxidation. The thinnest possible layer of liquid travels over an extended surface charged with the appropriate micro-organisms and continuously exposed to air. From the point of view of the microbes themselves nothing could be better adapted to their requirements. They have a constant regulated supply of food, never ceasing, but never much in excess, they have an abundant supply of oxygen, also constantly renewed, and the products of their action are as constantly removed. Such a filter will work continuously apparently without limit, and will, indeed, improve daily over a long period so long as the necessary conditions are not infringed.

The description of the whole plant naturally divides itself into three parts, relating respectively to the supply channel, the distributor, and the filter.

1. The supply channel is a gutter in direct connection with the sewer or tank outlet. Its margins, which are at the same level and

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* *Loc. cit.* p. 394.

The three essential points in the construction of this filter are, then, the arrangement of the floor, the uniformly coarse grade of the medium, and the freedom of the latter from dust and fine particles, the object being to maintain the liquid in sheet formation until it is actually outside the filter. Any attempt to carry out the principle of the continuous sewage filter with the usual construction of the intermittent filter or contact bed, however well provided with vertical aërating pipes, will meet with but very temporary success.

It will be shown later that the oxidising power of the continuous filter increases with the depth, but in a more rapid ratio; in other words, more than twice the quantity of sewage can be dealt with per yard of surface by doubling the depth of the filter. Consequently it is of much importance to conserve as much as possible the fall available on a given site; and as the loss of head involved in modern tank treatment and in the use of the distributor is merely nominal, it should always be possible to construct the filter of a depth within a few inches of the difference between the levels of the intake and outflow of the works. For the same reason it is a mistake to sub-divide the bed of the filter horizontally, any air spaces meaning merely the loss of so much aërating surface.

At the same time it must be understood that there is no minimum depth for the filter. Quite an appreciable change can be effected in even so small a distance as six inches, whilst two feet is quite a practicable depth for the bed where no more can be obtained; the necessary extension of the surface, however, means additional outlay. In many works there is no fall available, and pumping is necessary whatever treatment is adopted. In such cases it will generally be found economical to increase the lift so that a filter of ten or fifteen feet in depth, and of proportionately small area, may be constructed.

On first setting the filter to work, little change is observed until about the third day, when the sewage odour disappears, though the chemical composition alters but little. Nitrification sets in about the eighth to the tenth day, and increases in vigour up to about the sixth week, when the filter is mature, and the effluent is not only capable of admission into any watercourse without risk of offence, but is in a condition to effect marked improvement in polluted water into which it may be discharged. The maturing of the filter appears to take the same course whether the tank effluent is applied continuously from the first, or at intervals, and is apparently unaffected by temperature, existing filters having been started under very variable conditions without any marked difference in the rapidity of development of nitrification.

The first successful filter of this type was erected at Horfield, near Bristol, in 1899, and the following table shows the results obtained from it:—

TABLE XV.

Analysis of Sewage Effluents derived from Stoddart's Filter.
(*Results expressed in Grains per Gallon.*)

	Exceptionally strong sewage. Oct. 20th, 1899.			Dry weather flow. Oct. 3rd, 1899.			Wet weather flow. Oct 6th, 1899.
	Sewage.	Tank effluent.	Filtrate.	Sewage.	Tank effluent.	Filtrate.	Filtrate.
Saline ammonia	35·63	10·08	6·3	6·832	2·698	1·295	·14
Albuminoid ammonia	9·15	·77	·26	·907	·319	·090	·035
Nitrogen as nitrates and nitrites	none	none	1·50	none	none	1·80	1·27
Oxygen absorbed 15m. at 80° F.	—	—	—	2·38	·616	·245	—
Oxygen absorbed 4hrs. at 80° F.	23·10	8·50	1·47	5·59	1·218	·490	—
Suspended solids	—	—	—	21·0	3·2	none	none
Appearance.....	opaque	opalescent	turbid with clinker *débris*, rapidly clears	opaque	opalescent	brilliant	brilliant
Odour	sewage	sewage	slight, earthy	sewage	sewage	slight earthy odour, not suggestive of sewage or unpleasant.	
Daily rate of flow; gallons per sq. yard	.. ..		576	....		1,416	1,800
Daily rate of flow; gallons per acre	....		2,787,840	....		6,853,000	8 712,000

The maturing of this type of filter is said to be remarkably rapid and apparently independent of seasonable variations. After the first three days of continuous flow the filtrate is said to be "perfectly sweet and free from sewage odour, but shows little chemical improvement." Nitrification would appear to set in about the eighth to the tenth day, and to increase in vigour daily until at the end of the second month the effluent begins to acquire that peculiar brilliancy

which is characteristic of waters in which nitrification is very active.

Mr. Caink, Messrs. Whittaker and Bryant, and others have adopted what is essentially a Ducat filter, but effect the distribution of the sewage upon it by means of rotating arms which are perforated with holes. When the flow of sewage escapes from these in jets the arms rotate after the manner of a garden sprinkler, and thus the liquid is spread over the bed in a succession of thin layers.

Messrs. Mather and Platt have modified the form of the arms by making them an open trough with holes in the bottom of the sides at intervals to avoid the possibility of the ordinary jet openings becoming choked with débris from the sewage.

In all these cases the preliminary settlement of the crude sewage, in either Cameron's closed tank or in an uncovered one, is necessary to prevent the solid matters going on to the beds or "filters," as they are frequently termed. It will thus be seen that the essential principle is the same: settlement of the detritus of the sewage in a container to effect preliminary solution of the solid matters, and the retention of the sand, &c., and the final aërobic treatment of the liquid and finely divided suspended matters which pass through the tank with the flow of sewage. In the Barking Creek experiments, already described, the retention of the heavy solid matters was effected in the precipitation tanks, and the subsequent purification effected on the beds.

The point for discussion appears to be how far the anaërobic action in the tank should be carried. Mr. Cameron's septic tank had a capacity equal to about eighteen hours' flow of sewage, and it was considered essential that it should be covered. Later experience has shown that a similar action is brought about in an uncovered tank. It was also originally assumed that the whole of the organic matters were destroyed

in the tank. It is now accepted that this is not entirely the case. Dr. Clowes found, in the course of his experiments at Crossness, that the percentage quantity of sludge which disappeared, calculated on the total solids, was 41·2, or, if calculated on the organic constituents, 71·4. (*See* p. 77.) These quantities seem to fairly represent the experience at numerous other places.

In the course of a series of examinations of the septic tank process at Belleisle, Exeter, I obtained the following results:—

Table XVI.

Septic Tank System of Sewage Treatment.—Exeter (Belleisle) Installation.—Summary of Analyses.

April and June, 1897.	Grains per gallon.											
	Oxygen absorbed from permanganate in four hours.	Ammonia.		Chlorine.	Nitrogen.		Suspended Solids.			Dissolved Solids.		
		Free.	Albuminoid.		As Nitrites.	As Nitrates.	Total.	Mineral.	Organic.	Total.	Mineral.	Organic.
Crude sewage, average of 12 samples.	2·028	3·778	0·212	5·0	—	—	24·5	10·0	14·5	29·9	14·0	15·9
Tank effluent, average of 13 samples.	1·405	2·763	0·175	5·1	—	—	10·8	3·5	7·8	30·7	16·1	14·6
Purification per cent.	30·8	26·9	17·5	—	—	—	—	—	—	—	—	—
Filtrate, average of 19 samples	0·388	1·705	0·078	5·3	0·253	0·353	Practically nil.			44·5	20·3	24·2
Purification on tank effluent per cent.	72·4	38·3	55·5	—	—	—	—	—	—	—	—	—
Purification on crude sewage per cent.	80·9	54·9	63·2	—	—	—	—	—	—	—	—	—

From the analyses of the crude sewage, it will be seen that the average quantity of suspended matters present was 24·5

grains per gallon. As the tank effluent contained an average of 10·8 grains, 13·7 grains per gallon must have remained in the septic tank. As the average daily quantity of sewage during the ten months, as measured by Mr. Martin, was 57,000 gallons, the total quantity of suspended solids arrested in the tank was equal to 150·7 tons of sludge of 90 per cent. moisture.

As the tank effluent contained 10·8 grains per gallon, and the coke-breeze filtrate practically no suspended matter, it is evident that at least 10 grains must have been arrested or rendered soluble by the bacterial action in the filters, thus accounting for 110 tons of sludge during the ten months.

Summarising the general results of this examination, it is clearly demonstrated that, equally with the Sutton system, this process is well adapted from the chemical and biological point of view for the efficient treatment of crude sewage without the aid of chemicals, sludge presses, &c.; and that by the combined system of tank and filter, a resulting final effluent is obtained from the Exeter (St. Leonards' District) sewage of a most satisfactory character, having full regard to modern requirements.

A careful series of tests was made with a view to ascertaining whether the biological action within the tank caused any alteration of temperature; this, however, did not occur, the average temperature of the outgoing tank effluent being the same as that of the incoming sewage. The average temperature of the filtrate, however (48 deg. Fahr.) was 0·7 deg. Fahr. higher than that of the crude sewage or tank effluent.

A microscopical examination was made of a sample of the leathery scum from the surface of the sewage in the septic tank. It consisted of granular débris with various organic remnants, such as the larva of an insect, spiral vessels, vegetable hairs, decaying entozoa, worms (Anguillulæ),

decaying confervæ and muscular fibre, the whole matted together into a gelatinous mass, and swarming with bacteria of various kinds.

It has been suggested that the use of a closed septic tank enables the gases given off during the anaërobic process to be collected and used for lighting and heating purposes. According to Mr. Fowler, the results of measurements made at Manchester indicated that about one cubic foot of gas was evolved from 100 gallons of sewage.* Mr. Clark, at Massachusetts,† reported on this point as follows:—

TABLE XVII.

	Temperature Fahr.		Gallons of gas per each 100 gallons of sewage passing through tank.
	Air.	Sewage.	
10 measurements, April 21 to May 1	54	51	4·6
14 ,, May 2 to May 22	55	52	6·3
22 ,, July 10 to July 20.....	80	74	8·4
October.....	65	65	4·5

Each measurement covered a period of 24 hours, except in a few instances, when the period was 48 hours.

In the course of a most thorough investigation on the action of the septic tank on acid iron sewage, carried on by Professor Leonard P. Kinnicutt and Mr. Harrison P. Eddy, which was published in the Third Report of the Connecticut Sewerage Commission, the quantity and quality of the gases evolved from the deposits in the tank were carefully examined,

* Annual Report of Rivers Department, 1901, p. 41.

† Thirty-second Annual Report of Massachusetts State Board, p. 373.

with the results set out in Table XVIII. The amount of sewage passing through the tank equalled 2,350 gallons per day :—

TABLE XVIII.

Month.	Temperature.		Gas. Cubic feet average per day.	Gas in gallons, per 100 gallons sewage.
	Sewage.	Effluent.		
October	67·1	65·4	9·15	2·912
November	61·9	57·8	6·43	2·046
December	52·6	51·0	2·95	0·9389
January	51·5	51·4	0·59	0·1878
February.....	50·0	—	0·69	0·2196
March	48·5	48·0	0·30	0·0954
April	49·0	48·0	0·80	0·2546
May.....	54·8	54·7	2·89	0·9198
June.....	59·2	60·0	8·12	2·584
July.....	72·6	72·5	24·21	7·705
August	75·1	75·1	14·55	4·631
September	68·0	67·8	13·08	4·162
October	64·0	62·8	12·17	3·873
November	56·1	54·1	11·65	3·709
December	48·15	49·3	1·80	0·5729
Mean	58·57	58·41	7·292	2·320

As might be expected, the quantity of gas varied with the character of the sewage and the temperature, and would of necessity vary largely, according to the depth of deposit in the tank and the degree of ventilation.

The percentage composition of the gases, according to different observers, was as follows:—

TABLE XIX.

Authority.	Carbon Dioxide = CO_2.	Oxygen = O.	Absorbed by Cuprous Chloride.	Marsh Gas = CH_4.	Nitrogen = N.	Hydrogen = H.
Exeter—						
DIBDIN	3·9	22·7	—	4·5	66·1	2·2
	3·5	8·0	—	40·1	42·2	6·2
RIDEAL*	0·6	—	—	24·4	38·6	36·4
Manchester—						
FOWLER†	6·0	—	—	73·0	16·0	5·0
Lawrence—						
GILL‡	3·4	0·5	0·6 (Reported as CO.)	78·9	16·3	—
Worcester (Mass.)—						
KINNICUTT AND HARRISON—						
October	5·6	1·9	0·8	75·3	16·4	
November	4·1	1·2	0·5	76·9	17·3	
December	2·5	2·0	0·4	69·5	25·6	
March	8·8	1·0	0·1	13·3	76·8	
April	9·8	0·9	0·2	28·4	60·7	
May	15·2	1·5	0·1	26·9	56·3	
June	17·0	1·2	0·2	52·1	29·5	
July	8·7	1·3	0·4	63·8	25·8	
September	8·0	1·6	0·4	57·8	32·2	
October	6·9	0·6	0·6	72·4	19·5	
November	6·3	0·7	0·3	79·2	13·5	
December	5·6	0·9	0·1	76·8	16·6	
Mean	8·2	1·2	0·34	57·7	32·5	

Messrs. Kinnicutt and Harrison remark on their results as follows:—"As is seen, we have never been able, with Worcester sewage, to obtain results comparable to those given by Dr. Rideal as the composition of the gas given off from

* "Sewage and the Bacterial Purification of Sewage," p. 72.

† Manchester Report, 1901, p. 41.

‡ Massachusetts State Board Report, 1899, p. 422.

the septic tank at Exeter. The smallest amount of carbon dioxide found by us in any analysis was 2 per cent., while the largest amount ever obtained equals 22 per cent. Hydrogen was found only in a very few cases, and the amount was always under 4 per cent., and the cases were so very few in which the analysis gave any hydrogen that we are inclined to believe that possibly the result was due to errors caused by too violent explosions of the gas mixture. We have also never been able to confirm Professor Gill's result as to the presence of carbon monoxide. In the process of analysing the gas there is an absorption varying from 0·2 to 0·8 per cent. when the gas is shaken with an ammoniacal solution of cuprous chloride; but this same gas, even when two liters were taken, failed to give either the iodine pentoxide reaction or the blood test for carbon monoxide."

The numerous trials which have been made of "open septic tanks" by utilising discarded chemical precipitation tanks has frequently led to serious complaints of nuisance, and when the effluents therefrom are spread on the surface of open filters the nuisance is still further enhanced. This has been held to be a serious bar to the use of distribution by means of sprinklers over filters. The suggestion has therefore been made to modify the size of the tanks and consequent time of passage of the sewage through them, so that this should not occupy more than from four to six or eight hours. Dr. Clowes found at Crossness that six hours was sufficient. Now that it is established that the whole of the sludge is not destroyed in the tanks, there is little reason for constructing these larger than is actually necessary to secure the prevention of grit, &c. going on the aërobic contact beds when these are used. Indeed, recent experience seems to trend in the direction of the possibility of the whole of the sludge, including the grit, being passed directly on to the primary or "coarse" bed, and there retained in distributing grips or carriers formed

by shallow depressions running "herring-bone" fashion over the beds and filled with finer material. The sewage deposits its grosser solids in these, and the water escapes through the porous sides into the beds. The deposit in the carriers is removed from time to time, and when thrown on a "spoil-bank" gradually dries up into a dark friable mass resembling loam, without nuisance of any kind. This is only a slight modification of the original coarse-bed treatment, originally introduced at Sutton, where, however, the deposit instead of being removed was dug into the bed, which continued to work satisfactorily for over five years until it was displaced in connection with the enlargement of the works.

In the case of Sutton, however, the sewage is of a purely domestic character, and is collected by a modern "separate system," so that it contained a minimum quantity of mineral débris. By means of the carriers even large quantities of grit would be retained and the beds kept in full working condition for prolonged periods. The expense of occasionally cleaning the carriers need not be large if proper means of conveying the deposit from them to the spoil-bank be adopted. This might best be by means of a trolley running on light rails down the length of the beds. The trolley could be moved forward as the work advanced and the consequent saving in labour be considerable.

It is now generally accepted that no process is capable of entirely abolishing the sludge difficulty, whether the work be carried out on a farm, a bacterial installation, or chemical process, and it is useless to attempt to do more than minimise the nuisance caused thereby and the cost of its prevention.

CHAPTER VII.

LAND TREATMENT *v.* BACTERIA BEDS.

In the case of farm irrigation with either the effluent or crude sewage, the process is essentially a bacterial one. The usual practice is to run the sewage or effluent, as the case may be, over fields prepared by means of drainage trenches, and by ploughing from time to time; and thus to allow the light suspended matters to be retained on the soil, where they are consumed by various organisms, bacterial and otherwise. The objections to this method are that, in the first instance, the expense of the land and laying it out is very considerable. After a time, when the land has become clogged with filth from the sewage, where this is used crude, a nuisance is apt to be created by the odours from the fields.

Another cause which often explains the unsatisfactory nature of the effluents from land which is to all appearance suitable and properly worked, is the fact that on the system of working with open underdrains the water sooner or later cuts its way through the soil in minute channels direct to the underdrains, and instead of coming into contact with the whole of the soil it flows away in almost as bad a condition as when it was put on the surface.

By the intermittent action in what, for convenience, are termed bacteria beds, this free escape of the water along lines of least resistance is prevented in consequence of the underdrains being closed during the process of filling the beds, as well as while they are standing full. The water must then

flow laterally to all parts of the bed, the full effective capacity of which is utilised.

Indeed, it is now clear that the success of all sewage farming operations, or what is generally known as "land treatment," is entirely due to the healthy aërobic working of microbic life, and that when Dr.—later Sir—Edward Frankland introduced his system of downward intermittent filtration, the success of the method was due to bacterial action. The following comparison of results obtained by sewage farms and the Sutton bacteria beds will show the work accomplished by the latter, which in respect to the degree of nitrification especially, is decidedly superior:—

SIXTH REPORT. RIVERS POLLUTION COMMISSION, P. 57.

Average Land Drainage Water from Sewage Farms.

Average organic carbon - - -	0·982 pts. per	100,000
Average organic nitrogen- - -	0·191 ,,	,,
Average nitrogen as nitrates, &c. -	0·756 ,,	,,

SUTTON EFFLUENT FROM FINE BED.

Average organic carbon - - -	1·016 pts. per	100,000
Average organic nitrogen- - -	0·172 ,,	,,
Average nitrogen as nitrates, &c. -	2·19 ,,	,,

RIVERS POLLUTION COMMISSION STANDARD FOR EFFLUENTS.

Organic carbon - - - -	2·000 pts. per	100,000
Organic nitrogen - - - -	0·300 ,,	,,

The effluents obtained at Sutton from strong "separate system" sewage were therefore comparable with those obtained from average sewage farms, and contained only about one-half the quantity of organic carbon and nitrogen considered permissible in a good effluent by the Rivers Pollution Commission.

[illegible] remarkable when the nature of [illegible]. With the view of putting the [illegible] possible, the following diagrammatic [illegible] point.

[illegible] the process which the sewage undergoes [illegible] with immediate sub-surface

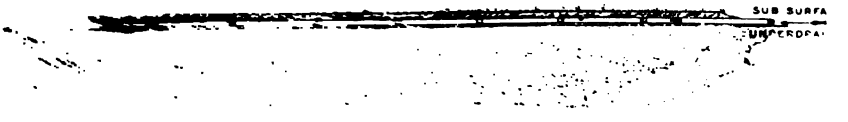


DIAGRAM A.

[illegible] In this case the solids are retained on the surface, [illegible] liquid passes almost immediately to the underdrains [illegible] less imperfect purification.

[illegible] shows the method of treatment on cultivated [illegible] underdrains at about 18 inches below the surface. [illegible] necessarily greater than in the first instance, [illegible] greater depth of soil; but undoubtedly

DIAGRAM B.

[illegible] way more or less directly by channels [illegible] of these fissures and channels [illegible] quantity of sewage which passes away [illegible]

Diagram C shows a similar state of things when the water is put on to a porous or gravelly soil deeply underdrained. For a while the results will be excellent, but in the course of

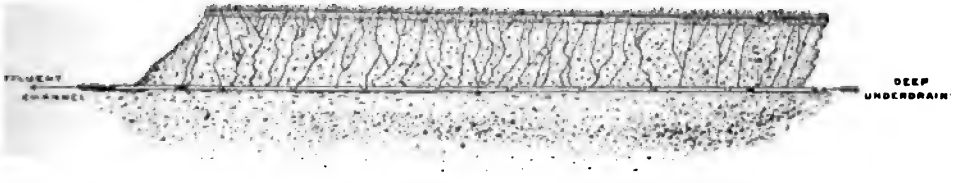


Diagram C.

time channels will be washed out, and through these the effluent escapes.

Diagram D shows the arrangement suggested for the more perfect treatment of the sewage by means of bacterial treatment. A certain quantity of the land is removed, and the sides and bottom of the "tank" or hollow thus created may be puddled with clay, or concreted if on a very porous soil, to make it water-tight. Drainage pipes are then laid on the

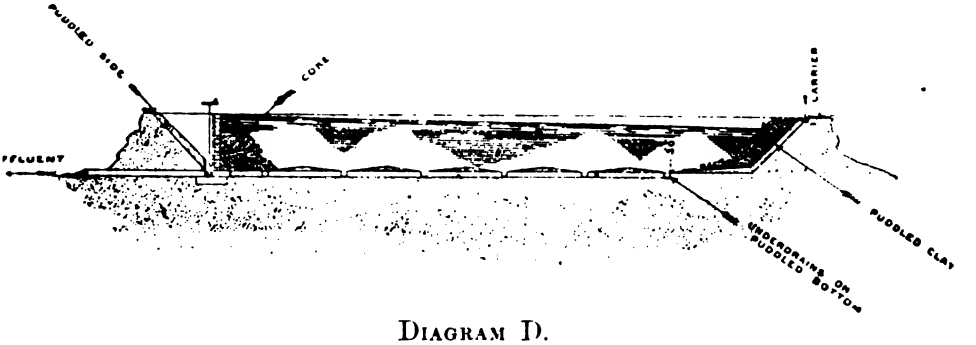


Diagram D.

bottom, and the space is filled with some coarse material, such as coke, clinker, broken granite, slates, chalk, burnt ballast, &c., coke, clinker, or ballast being preferred, as having

rougher surfaces, and entangling considerable quantities of air when the bed is refilled after standing empty. A penstock or sluice is fitted on the outlet drain, in order to lock the sewage in the bed for a definite time, as already explained. By this means the sewage is brought into contact with each particle of which the bed is composed, instead of being allowed to find its way directly to the underdrains. When a sufficient time has elapsed, the effluent is allowed to escape on to a similar bed at a lower level, but filled with fine materials. Here it undergoes the second "bacterial" treatment, and is ultimately discharged in a sufficiently purified condition.

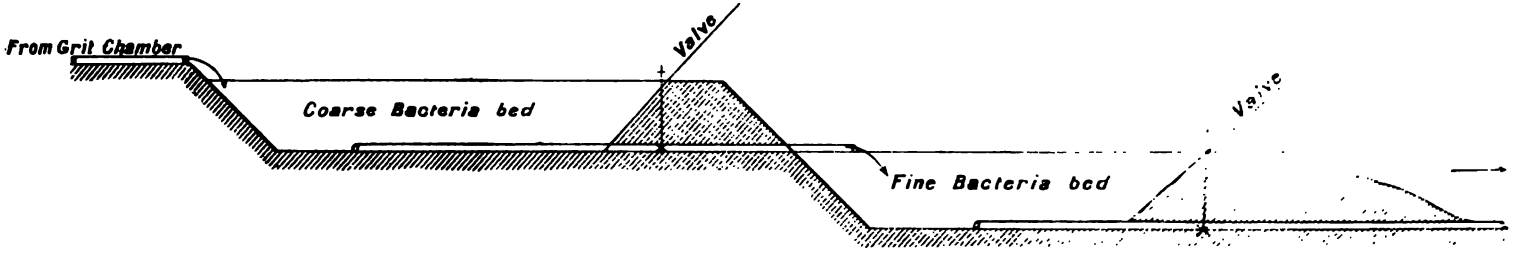
A typical pair of beds is shown in diagram E. It will thus be seen that a coarse bed treatment of the crude unsettled sewage is really equivalent to broad irrigation, and that on the fine bed to effluent irrigation, but starting in this case with a better effluent than is usually obtained by means of chemicals; and thus the effluent from broad irrigation on a coarse bacteria bed is well fitted for the second treatment by effluent irrigation on a fine bacteria bed.

From these considerations it will be seen that the "bacterial process" worked out at Barking Creek and Sutton is *land treatment*, but concentrated, accelerated and controlled, and therefore effective and economical; whilst "land treatment" as generally practised is haphazard, uncertain, and expensive.

The provision of land as a final safeguard may be met most completely by a third fine bacteria bed or a sand filter—in other words, by an area of land properly prepared and drained, and so arranged that all the effluents from the previous beds must pass through it; thus securing triple land treatment, but on an area of land considerably less than that usually employed.

Under the conditions of broad irrigation, or of land treatment of a chemical effluent, the water is charged with a

Diagram E.



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certain amount of flocculent matter. When this is spread over the land day after day a matted deposit is formed on the surface, resulting in the clogging of the pores of the soil, and its consequent "sickening" at an earlier or later period. Every gardener knows the great importance of freely hoeing the ground in order to promote "growth;" in other words, to allow the ground to *breathe*. Nothing is more fatal to free vegetation than daily watering the ground, in hot weather especially, without equally frequent hoeing, and thus causing the soil to cake into either a hard, close surface, or, in the case of too much water, turning it into a dismal swamp, equally impervious to air. As the frequent hoeing of acres of farm land would be all but impracticable, on account of the expense, it becomes a matter for question as to whether the desired result cannot be equally well or even better attained by other means.

As regards land filtration, one condition which often gives rise to unsatisfactory results when the levels are unfavourable is that when a river is in flood the outfall drains are partially closed, and thus the water cannot drain away with sufficient rapidity, and the field or plot in question becomes waterlogged, air cannot get into it, and an unhealthy condition arises, as is evidenced by the wholesale drowning of the worms in the soil. In no case should the water be allowed to stand above the surface of the soil, or within it, for a longer period than a few hours.

The extent to which land can treat an effluent free from suspended matter can be estimated from the consideration that one acre of land, underdrained, five feet deep, will have a total cubic content of 217,800 cubic feet. If the quantity of water the land can take be estimated at only one-tenth of the total cubic content, then one acre five feet deep will take at each filling 136,125 gallons.

The results of experiments at Leicester and Croydon have

shown that the best results on land are obtained by allowing the sewage to pass through a detritus tank, then on to coarse contact beds, and thence to the land.

In watering soil, undoubtedly the best way is to arrange so that the liquid is absorbed into the ground by capillary attraction without disturbing the surface, which would thus remain open and friable, and consequently in the best "breathing" condition. This result can be attained by the system of first trenching the ground, if clay, with a plentiful admixture of ashes, and then cutting trenches throughout its length, say, ten yards apart. Between these trenches, down the centre of the beds, as the intervening ground may be termed, agricultural drainage pipes should be laid at a proper depth, just below the level of the bottom of the trench, or deeper, if the subsoil is of an open and porous character. The seed or plants should be sown or set on these beds, and a daily charge of effluent, free from suspended matter, such as that yielded by the fine coke-breeze beds worked on biological principles, turned into the trenches. This clear water will be soaked up by the intervening earth, which will thus be kept moist in a degree exactly suited to the exigencies of the plant life, and the excess of fluid will find its way through, say, five yards of soil, to the drainage pipes, thereby undergoing further purification in a thoroughly effective manner.

When the climatic conditions are such as to render the application of the effluent to the land inadvisable, it can be sent direct into the river, as the degree of purification already effected in the bacteria beds will be ample. By so doing the manurial constituents in the liquid, viz., the phosphoric acid, potash, and nitrogen, will not be employed on the land, but as the water will not be exerting its functions in "drowning" the land, they will be at least doing no harm. The great advantage of the bacterial system of treatment is that the nitrogen and other matters in their original foul condition

are converted into a state in which they are best fitted for the support of vegetable life, just as they appear in an artificial manure. The process which takes place is precisely that which the farmer and gardener employ when they allow their crude fresh manure to "rot," as they term it. Until this is accomplished they do not think of spreading it on the land. In the same manner, the crude sewage matters are allowed to undergo a process of "rotting;" in other words, disintegration and oxidation by bacterial agency on specially prepared beds.

In consequence of the freedom of the bacteria bed effluents from suspended matter the field trenches will remain pure and sweet, and the land will not become choked with foulness, commonly described as "sickened," and thus with the exercise of proper care the process may be continued indefinitely with the greatest success.

As an instance of what may be done in this way, the experiments made in mint growing at Sutton, Surrey, under the direction of Mr. C. Chambers Smith, may be quoted. The land was laid out as above described, planted with the ordinary field mint, and irrigated in the trenches, a small plot at the head of the field receiving effluent on the surface in the usual way. The crop of mint obtained was very good, except in that portion which received the effluent on the surface. Here the plants were far between, stunted, and scorched up in appearance, whilst those in the beds between the trenches were thick and tall, and full of leaf down to the bottom of the stalk. The yield of oil from the four acres under cultivation in 1898 was 119 lbs., or 29 lbs. 14 ozs. per acre, which produced a revenue of £145 15*s.* 6*d.*, or £36 8*s.* 10½*d.* per acre. The cost of distillation was equivalent to £4 8*s.* 9*d.* per acre.

From this experiment it is clear that irrigation over the surface is a great blunder when a good effluent is obtainable;

whilst irrigation by means of trenches is not only most efficacious, but profitable in no small degree.

If land can thus be made to yield such a profit, the action of the Local Government Board in insisting upon the provision of a suitable area will turn out to be of the greatest service to the ratepayers. Under the generally existing conditions sewage farms are a great loss and inconvenience, and are viewed with widespread dislike by the public at large. The arrival of the bacterial system on the scene promises to remove the difficulty and turn our land into smiling fields absolutely free from all suspicion of cause of complaint. In the place of sodden ground, yielding nothing but rank grass and evil-smelling miasma, we shall have dry top soil covered with a healthy vegetation, the leaves of which have never known sewage, nor the roots either, for the liquid which reaches them will no longer deserve that name. The productive power of the land will be greatly enhanced, and the atmosphere kept as sweet as if no such thing as sewage had ever troubled a much puzzled committee.

CHAPTER VIII.

MANCHESTER EXPERIMENTS.

In May, 1898, the Corporation of Manchester appointed three experts, viz., Mr. Baldwin Latham (engineer), Dr. Percy F. Frankland (bacteriologist), and Dr. W. H. Perkin, Junior (chemist), to advise as to the best method of purifying the sewage of Manchester. After many careful experiments on a working scale, these gentlemen reported on the 30th October, 1899, the results of the investigations in detail, and formulated their conclusions as follows:—

1. That the bacterial system is the system best adapted for the purification of the sewage of Manchester.

2. That any doubts which may have arisen in the first instance as to its suitability, owing to the presence in Manchester sewage of much manufacturing refuse, have, through the convincing results of our experimental enquiry, been entirely banished.

The results obtained have altogether exceeded our expectations as to the possibility of purifying a manufacturing sewage, inasmuch as it was previously a matter of common belief that in such a liquid only a most insignificant amount of nitrification could be induced.

3. That inasmuch as a bacterial contact bed can only effect a definite amount of purification in a single contact, it becomes necessary, in order to carry the purification beyond this limit, to apply the effluent to a second bed, in which again a further definite amount of purification can be effected. Hence, for obtaining a high degree of efficiency in the bacterial purification of sewage, a system of multiple contact is generally necessary. Thus, it may be taken broadly that in the first contact 50 per cent. of the dissolved impurity is removed, and that in the second contact 50 per cent. of the impurity still remaining in the effluent is disposed of, and so on.

4. In order that a bacterial contact bed may exercise its full powers of purification, it is necessary—

(a) That it should be allowed sufficiently frequent and prolonged periods of rest;

(b) That the sewage applied to it should, as far as possible, be free from suspended matters;

(c) That the sewage applied to it should be of as uniform a character as possible.

5. The above conditions are secured by passing the sewage as it arrives at the works through an adequate system of screens, catchpits, and tanks. Such an arrangement has the further important advantage of leading to the development of those anaërobic or septic processes which resolve into gaseous and soluble products the organic suspended matter present in the sewage. A large proportion of the sewage-sludge which would otherwise accumulate, and the disposal of which is the source of so much difficulty and expense, is thus abolished. The above anaërobic or septic process is found to take place as effectively in an open tank as in a closed one.

6. The capacity of bacterial contact beds has been found to remain practically constant after they have been in operation for a period of three months. This capacity is best referred to the empty tanks, the measurement being taken to the line which corresponds to the surface of the clinkers which are subsequently put in. The constant water capacity of the beds has been found on this basis, in round numbers, to be about one-third of the tank capacity.

7. With regard to the amount of sewage which can be purified by a given bed without the latter being overtaxed, our prolonged experimental enquiry has shown that each bed may safely receive four fillings in the twenty-four hours, provided the sewage has undergone the preliminary subsidence and septic preparation in tanks, and that the bed is accorded about one day's rest in every week. In the event of a bed having been unduly taxed, its efficiency is only temporarily impaired, and can be restored by a few days' repose.

8. We have shown that storm water may also be satisfactorily dealt with by means of an accelerated bacterial treatment, which can be brought into operation as soon as the sewage is sufficiently dilute. As, however, until about two hours after the commencement of heavy rain there is no abatement in the concentration of the sewage, it will be generally necessary to provide for the storage or separate treatment of the first flow.

9. Our experiments show that the bacterial system of treatment is efficacious at all seasons of the year, the temperature of the sewage being sufficient both to prevent any stoppage of the beds by the formation of ice, and also to maintain the necessary activity of the bacteria even in the coldest weather.

In view of the experience gained and set forth above, we beg herewith to make the following recommendations:—

1. That the sewage, as it arrives at the works, be submitted to an efficient process of screening, and that it be then passed through the present open tanks. These tanks should be provided with submerged walls and floating scum-boards, so as to retard the flow of the mineral and organic matters in suspension. In the event of the present

screening machinery proving insufficient to remove the heavier mineral matters in suspension, it would be desirable that four roughing tanks should be added to the present tank arrangements, or that four of the existing tanks should be converted into such roughing tanks, and that four additional tanks should be provided to take their place.

2. That the effluent from the open tanks be passed through the double contact beds.

Of these double contact beds we estimate that there should be an area amounting in round numbers to sixty acres, exclusive of retaining walls, roads, &c. This estimate is based on a dry-weather flow of thirty millions, and that each acre, being laid out in beds of 3·33 feet depth, with four fillings per twenty-four hours, would be capable of dealing with half-a-million gallons of sewage in round numbers, allowing for one day per week rest.

The bacteriological or biological beds would be constructed in pairs, high level and low level, of about half an acre each, for the purpose of being able to get the sewage quickly upon them. Division walls between the pairs of filters would be made to serve the purpose of both a sewage carrier and a drain. The upper channel, conveying the sewage on to the higher level, would also have below it a drainage channel for conveying away the effluent and taking it to the low-level beds, the arrangement, however, being such that either crude sewage or effluent can be turned upon the lower beds.

The arrangements for draining the filters now proposed to be constructed are simply to form proper channels in concrete, covered with perforated slabs, without the use of pipes, and so constructed that the effluent channels can be kept filled with the effluent, and thus avoid crude sewage passing into them, or that they may at any time be completely drained into the main pick-up channel.

Mechanical arrangements will also be made for the purpose of distributing the sewage over the surface of the beds, which is a matter of some importance; and the construction will enable the whole of the openings on to one bed to be simultaneously opened or closed, so as to avoid loss of time by the men passing from one opening to another.

The final effluent from the various filters would be collected and conveyed into the existing deep-water culvert which passes through the lands at Davyhulme, and would thus convey the effluent into the Manchester Ship Canal below Barton Lock.

3. With regard to the material most suitable for the bacteria beds, we should recommend that it consist of clinkers, of such a size as to pass a 1½-inch mesh and to be rejected by a ½-inch mesh. Efficient means must be provided for rapidly filling and discharging the beds. The beds should be so constructed as to allow of each being used independently.

4. During the occurrence of a storm the flow of sewage should be dealt with in the system of tanks and double contact beds. The excess of flow, after passing through the roughing tanks, should be taken to specially prepared bacteria beds of an area which, we provisionally estimate, will have to be of at least twenty-five acres in extent.

As a safeguard against excessive quantities of storm water passing down at any time, the present sewage tanks may have an increased depth of water put upon them. At present the tanks have a capacity of 12·3 million gallons per day, and this may be readily increased to about 15 million gallons per day by raising the walls of the tanks.

When a tank is required to be cleansed, which will be very seldom the case, it will be necessary for part of the liquid contents to be pumped into the sewage channels, so as to be capable of being treated in other tanks.

Finally, we may state our confident opinion that with the system of bacteriological treatment of the sewage of Manchester set forth above, an effluent will be produced which will not only conform with the Mersey and Irwell standard, but which will also materially improve the condition of the Ship Canal. Furthermore, as this system does away entirely with the use of chemicals, and at the same time to a very large extent reduces the volume of the sludge to be dealt with, it is obvious that much of the present expense will be saved by its adoption, and this saving may be taken as a material set-off against the cost of the construction of the proposed works.

As a result of these conclusions, the Corporation of Manchester applied to the Local Government Board for permission to borrow £160,000 for the purification of 23,000,000 gallons of sewage daily on bacteria beds.

In his evidence at that inquiry Dr. Percy Frankland stated that the chemical treatment of Manchester sewage should be abandoned, and a real purification process should be introduced. Bacteria effect the purification. Land treatment is the same as bacterial treatment, but the conditions are haphazard; whilst in the other case they are accurately ascertained beforehand. It is simply a development of land treatment, nothing else. As a consequence of their visits to other places they instituted these experiments. They found that they could treat the very strongest sewage which they

have had from the sewers at Manchester. The purification by the combined beds was 82·2 per cent.

Mr. Baldwin Latham, M.Inst.C.E., said: The great principle is to fill the bed as quickly as possible. The air follows the water, and there is no necessity to pump air into the beds. The oxygen in a gallon of air is seventeen times as great as that which is required to oxidise the fluid. The beds have been worked three times a day regularly, and four or five times if necessary. They have enormously improved in working. They would be less affected by cold weather than would land filtration. The process will dispense with chemical treatment altogether, and will deal with the storm water.

Dr. Perkin said: I have come to the conclusion that the bacteriological system is the only feasible system.

Major-General Crozier: As regards Manchester?

Dr. Perkin: "No, as regards the world. . . . . I think we shall find that the clogging will not be so serious as is usually supposed to be the case, and that the crude sewage can then be run on to the first filter without any sedimentation at all. That would do away with the sludge steamer, the expense of which is £7,000 per annum."

The view expressed by Dr. Perkin at that stage of the experiments is one which it was originally hoped might be found to be the case in regard to a large number of instances; but it is clear that it can be only accomplished when careful fine screening is resorted to, and the surface of the beds divided into distributing channels which collect mineral and highly resistant material. By this means the necessity for the open tank for collecting the grit and subjecting the organic matter to anaërobic action, with the risk of the production of most foul odours, is done away with. The use of such distributing channels has been long employed in connection with land treatment, and it remains to be seen

how far their intelligent use will assist in effecting the solution of the sludge difficulty.

Mr. Baldwin Latham is at present of opinion that "controlled filtration, as in use at Friern Barnet for the last seventeen years, will in future be the proper system for adoption, as the contact is very much longer on the beds, the air is always present, and the results of purification are much more satisfactory, all the effluents contain a much larger amount of nitrates, enormously in excess of that got in ordinary contact beds, yet the quantity treated is equal to that of any set of double contact beds."

As a result of the above-mentioned inquiry, the Local Government Board admitted the principles of purification involved in the experts' scheme, but required certain conditions to be fulfilled before granting the loan, the chief of these being the provision of ninety-two acres of beds instead of the sixty acres recommended by the experts, and the final treatment of the filtered effluent upon land.

The City Council instructed plans and estimates for both schemes to be laid before them, and finally decided to fall in with the requirements of the Local Government Board.

Full borrowing powers have now been granted, and the works of construction are being rapidly pushed forward, the beds being brought into use as soon as completed.

The work of experimental treatment has been carefully continued under the able direction of Dr. Gilbert J. Fowler, superintendent and chemist, and Mr. James P. Wilkinson, engineer to the corporation. By the kind permission of the Rivers Committee of the Corporation of Manchester, I am enabled to give the following particulars of the position of the Manchester Sewage Works up to July, 1902, which are abstracted from a report prepared jointly by Dr. Fowler and Mr. Wilkinson, which was presented to the committee by the chairman, Sir Bosdin T. Leech.

Quantity and Character of Sewage.

The drainage area of Manchester, including portions of Audenshaw and Stretford, is 11,800 acres.

The population coupled-up to the sewers was estimated in March, 1902, at 564,000, whilst the rateable value for sanitary purposes was £3,523,000.

There are upwards of 1,700 miles of sewers within the City area; these vary in size from 14 ft. by 10 ft. 6 in. to 9 in. in diameter.

The water supply per head of the population is estimated at twenty-nine gallons per day, of which sixteen gallons are used for domestic purposes, the remainder being available for trade.

The number of pail closets on March 31st, 1902, was 73,915, and the number of waterclosets 45,686. The number of street soughs, estimated in 1896, was about 90,000.

The rainfall in Manchester, taken at Oldham Road during the past three years, has been as follows:—

1900	32·585 inches.
1901	34·471 ,,
1902	28·645 ,,

Including storm water, the average daily flow of sewage for the year ending March 27th, 1901, was 34,071,019 gallons, whilst the average daily dry-weather flow was 25,700,000 gallons.

A comparison of the dry-weather flow on different days of the week gives the following results:—

Day of the Week.	Average Rate per 24 hours. Gallons.
Tuesday	27,539,000
Friday	27,458,000
Wednesday	27,268,000
Thursday	27,011,000
Monday	25,364,000
Saturday	24,336,000
Sunday	20,924,000

The greatest daily flow recorded was on Tuesday, August 7th, 1900, when 163,624,000 gallons passed down to the outfall works. The greatest rate of flow registered was from 9 p.m. to 11 p.m. on August 6th, 1900, when it reached 222,625,000 gallons per twenty-four hours.

These excessive flows were in part caused by floods in the Rivers Irwell and Medlock. These floods backed up some of the storm-water overflows, provided at certain points on the main drainage system, into the main sewers, thus considerably augmenting the flow at Davyhulme.

The dry-weather flow is considerably in excess of the theoretical quantity deduced from the water supply. The greater part of this excess is accounted for by subsoil water entering the sewers; the rest is sent in by those manufacturers who use water from wells and other sources.

Under normal conditions the trade effluents form about 5 per cent. of the total sewage received at Davyhulme. Much of the impurity thus contributed is in solution, and is for the most part unaffected by the lime and copperas treatment in use at the outfall works.

The following are among the chief trade effluents which are discharged into the Manchester sewers:—Ammonia recovery liquor, containing ammonia, sulphocyanates, traces of pyridine and other tar products; benzol washings, containing sulphonic acids of naphthalene, &c.; also the waste liquors from breweries, dye and bleach works, galvanising works, grease refineries, tanneries, rubber goods works, tripe-dressing works, and mineral water manufactories.

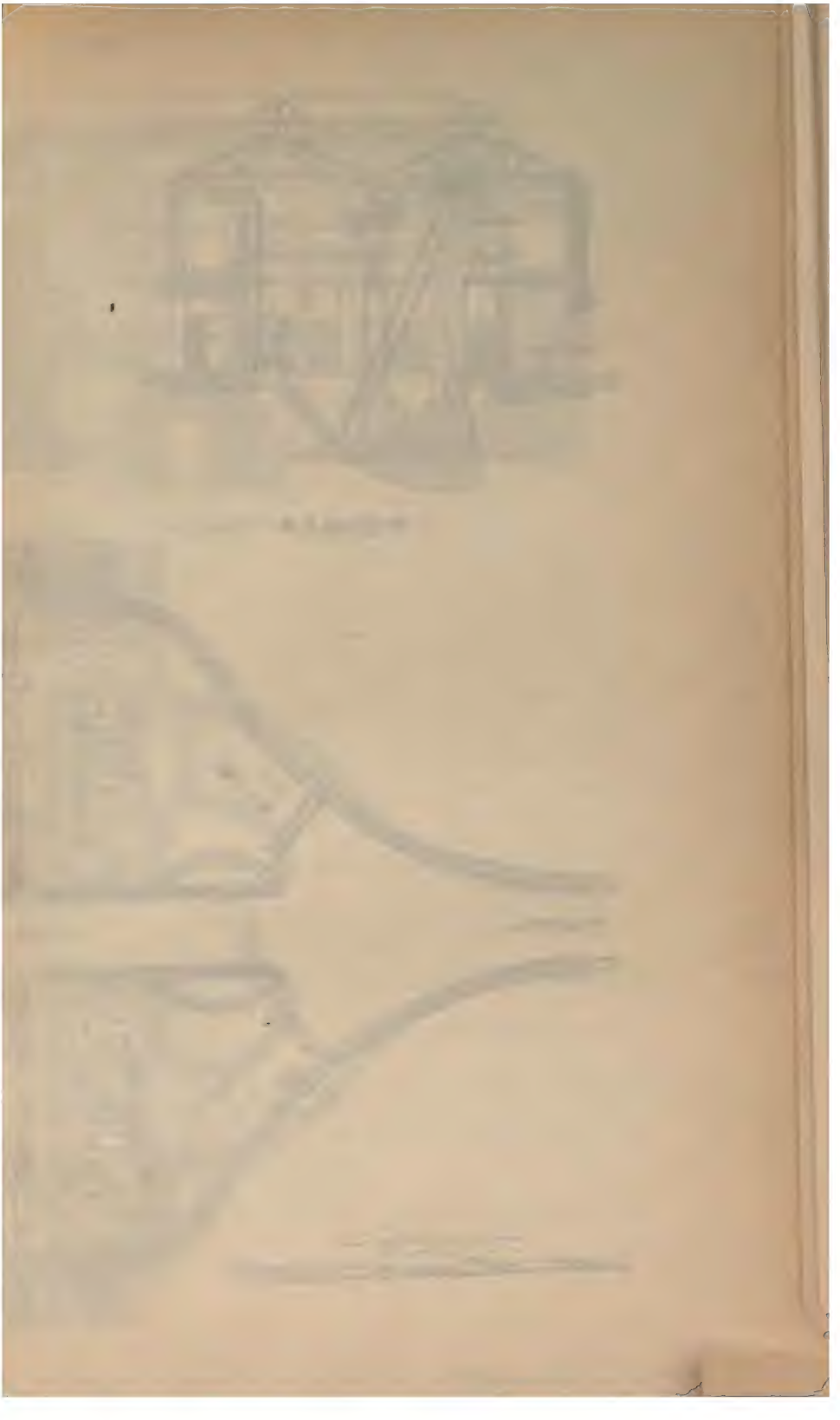
The above effluents, although in most cases non-putrefactive, and in some cases even antiseptic, greatly increase the analytical numbers.

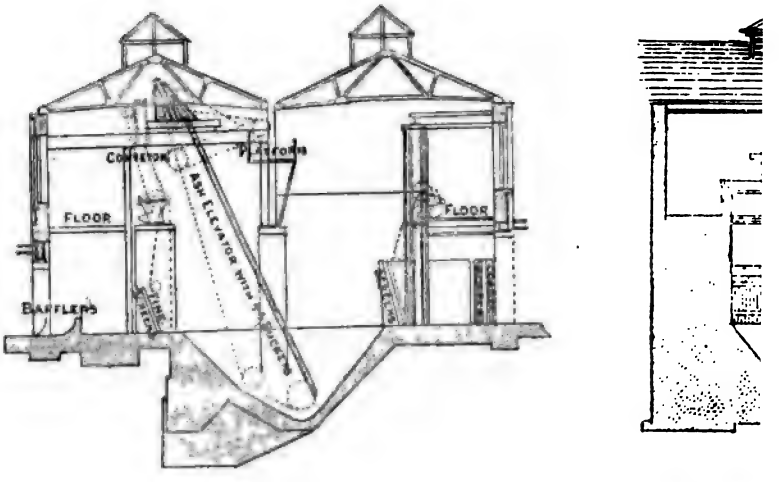
Description of Sewage Outfall Works.

The present works, which first came into operation in the spring of 1894, are designed for the treatment of sewage by chemical precipitation. The sewage as it reaches the works passes through a system of screens and catchpits designed to intercept the coarser floating matter and heavy detritus. It is afterwards treated with lime and copperas. These together form a flocculent precipitate which carries down the lighter suspended matters, causing them to settle in the tanks, the clarified effluent flowing into the Ship Canal. The precipitated matter or sludge is pushed from the tanks by manual labour into channels leading to two ejectors, from which it is forced under air-pressure into two storage tanks near the banks of the Ship Canal below Barton Locks. From these tanks it flows by gravity into the sludge steamer, and is deposited at sea beyond the Mersey Bar.

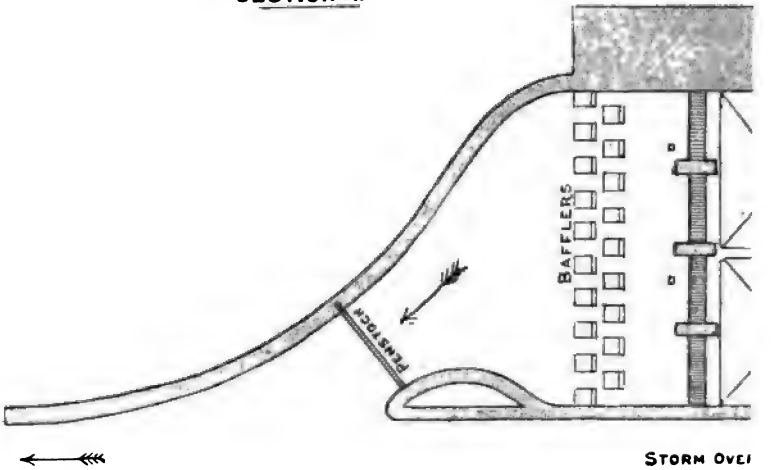
Site of Works.

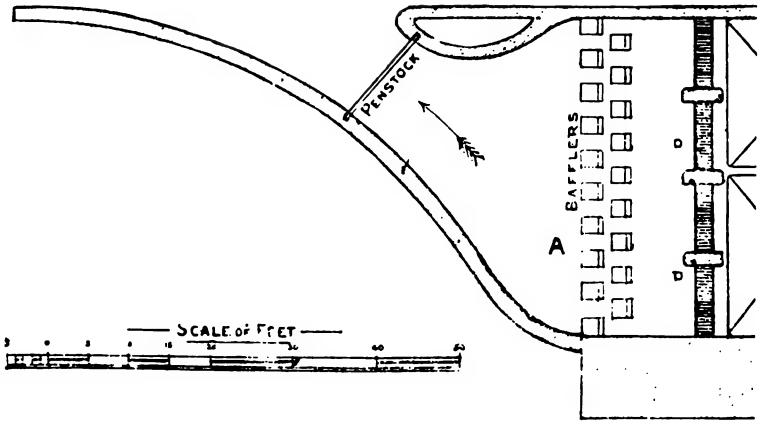
The sewage outfall works are situate on the south side of the Manchester Ship Canal, which they adjoin. There is a landing stage and jetties below Barton Locks for the purpose of loading the new sludge steamer; and above the locks there is a wharf, with steam cranes and weigh-bridge, at which coal, chemicals, and materials for



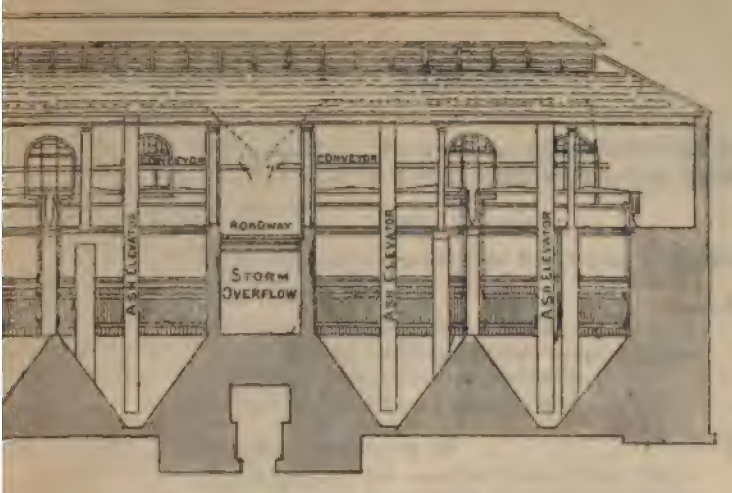

FLOOR
FLOOR
BAFFLERS
ASH ELEVATOR WITH BUCKETS

— SECTION A.B —

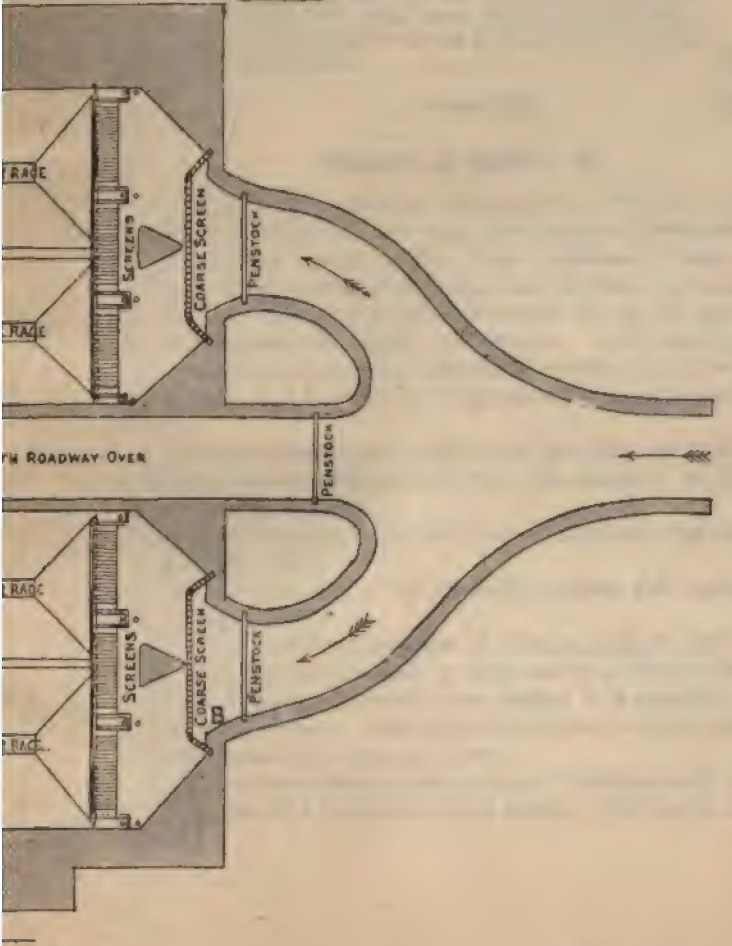

BAFFLERS
PENSTOCK
STORM OVEI


PENSTOCK
BAFFLERS
A
SCALE of FEET

F.



SECTION C D



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construction are landed. The works are approached on the south-east side by a private road 30 feet in width leading from Barton Road to the main entrance.

Area of Land.

The total area of land comprising the Davyhulme works amounts to 176·5 acres, and is divided up as follows :—

	Acres.
Land occupied by precipitation tanks	7·5
Land occupied by buildings, sludge tanks, &c., and land occupied in connection therewith	15·0
Land occupied as wharves and lay-byes	5·0
Total area of land occupied.....	27·5
The area of land not occupied by buildings, tanks, &c., and which is available for use, but includes existing roads, railway and embankment, disused river bed, the 26·25 acres laid out as irrigation area, and the bacteria beds at present in the course of construction.....	149·0
Grand total	176·5

Removal of Detritus, &c.

Owing to the fact that the street gullies in Manchester are, in general, unprovided with silt traps, the sewage of Manchester, especially in time of storms, contains large quantities of heavy detritus from the streets, together with cinders and sometimes coal from boiler-houses, &c. This was formerly barrowed out of the precipitation tanks at considerable trouble and expense. Much floating matter, such as cotton waste, rags, and garbage of various sorts is also present, which would tend to choke the sludge plant if allowed to pass into the tanks.

A system of screens and catchpits has therefore been devised and erected for removing this material from the sewage as far as possible before chemical treatment.

The present arrangements have been in satisfactory operation since January 26th, 1900.

Plans and elevations of the screening chamber and machinery are given in diagram F.

The plant consists of a system of screens, catchpits and elevators, which is in duplicate, one set on each side of a central storm relief channel. One set only is used when the flow is at its lowest, or when repairs are necessary. Both sets of machinery are used during the hours of heavier flow or during storms.

At the entrance to the screening chamber is a fixed screen formed of bars 4½ inches by 1 inch, with 6-inch spaces. This screen serves to

arrest all large pieces of timber, &c. which may be carried down the sewer from where constructional work is in progress, or any other large floating matters which might tend to injure the finer screens. This screen is cleared by hand.

Between this screen and the next is a cut-water of concrete cased in iron plates for the better distribution of the sewage over the screens and catchpits.

The second screen extends the whole width of the screening chamber, viz., 37 feet, but is formed in three sections, each of which can be worked independently. It is constructed of $\frac{3}{4}$-inch iron bars with $1\frac{1}{4}$-inch openings. This screen is mechanically cleaned by tines attached to channel-iron bars, which are fixed to endless chains working on sprocket wheels at each end of the section of the screen. As the chains revolve the tines pass between the openings in the screen. The distance between the tined bars is such that two of them traverse the screen at the same time. The rate of speed of the cleaning bars with tines is $1\frac{1}{2}$ feet per second. The floating matter arrested by the screen is carried by the tined bars to a point above the screening chamber floor immediately over a wrought-iron channel.

On passing over the sprocket wheels the tines recline to a vertical position, and any matters which tend to adhere to the tines are swept off by means of a brush into the wrought-iron channel. The brush extends the whole length of the section of screen, and is fixed on a shaft actuated by a lever and counterweight for reversing the motion.

The wrought-iron channel is cleaned with a squeegee, and its contents loaded into wagons which pass through the centre of the chamber, immediately over the storm relief channel.

The third screen is very similar to No. 2 (described above), with the exception that no brush arrangement is attached for cleaning, and the mesh of the screen is $\frac{1}{2}$-inch, the bars being of $\frac{3}{4}$-inch metal. The screen is divided into four independent sections.

Both No. 2 and No. 3 screens are surmounted with headstocks, carrying the necessary sprocket wheels and driving pulleys. The machines are driven by cotton belts from a counter-shaft overhead with fast and loose pulleys, and the necessary striking gear.

The elevators or dredgers are for dealing with the heavier matter which is deposited in the two catchpits situate between the second and third range of screens. The catchpits are in the form of hoppers, each side inclined to a common centre or race, in which the elevator buckets work. These buckets are attached to an endless chain actuated by a sprocket wheel in the headstock, which is fixed some distance above the floor of the screening chamber. The buckets are formed of $\frac{3}{16}$-inch steel plates, with semi-circular bottoms and rounded nosings, and

measure over all 16 inches by 8 inches and 8 inches deep. On the back of each bucket a steel-plate slide, 20 inches by 4 inches, is riveted on. This slide keeps the bucket in position when full by working in two angle-iron slide rests or guides, which are fixed to the bottom of the pit and to the headstock. The buckets are perforated with small holes for draining the dredged matter.

The endless detachable chain on which the buckets are fastened passes to the bottom of the pit, and is kept in position there by a guide wheel and sprocket wheel fixed on stone bases.

The headstocks are fixed on steel girders of a section of 75 lbs. per lineal foot, with transverse girders 40 lbs. per foot. The headstock frame is of cast iron, with sprocket wheels 2 feet 3 inches in diameter and pinion wheels of steel. There are a pair of sliding blocks to each headstock, with square threaded spindles and wheels for adjustment, the whole being similar to a hoisting crab. This machine is driven by a 36-inch pulley with 5-inch face, actuated by a cotton webbed belt from the main line shaft. There are fast and loose pulleys on all the headstocks, with proper striking gear, so as to allow of them being worked at will.

When these machines (four in all, one for each catchpit) are working, the buckets tip on passing over the sprocket wheel in the headstock into a hopper, by which the detritus is conducted into a metal channel or conveyor. Scrapers, attached at end to endless chains, push the detritus along this to a point over the central tramroad above mentioned into a wagon there placed for its reception. These endless chains are provided with detachable and attachment links passing over sprocket wheels, actuated from a shaft.

By means of the machinery and catchpits described, about ninety tons per week of solid matter are removed from the sewage in dry weather. In time of storm as much as fifty tons has been removed in twenty-four hours.

An average sample of detritus was found to consist of a large proportion of sand, fine coal and cinder, a fair amount of coal in moderate-sized pieces, also gravel, clinker, small pieces of brick, wood, leaves, &c. Altogether there was about 35 per cent. of combustible matter in the dried sample, of which about 7 per cent. was coal, which could easily be picked out by hand.

A rough experiment has shown that this material, if mixed with the garbage from the screens and allowed to drain, can be burnt with about 25 per cent. additional fuel. To obtain clinker from the mineral matter would probably require a forced draught.

Further investigation will be made as to the most satisfactory means of disposing of screening-chamber refuse. If it is found that this can be economically burnt in a destructor, a constant supply of clinker

could be obtained, which would be of value for the bacteria beds, and at the same time a material which tends to become a nuisance in hot weather would be disposed of in an inoffensive manner.

Tanks. (*See also* p. 142.)

The precipitation tanks are eleven in number; two are at present being used as septic tanks. Each precipitation tank is 300 feet long and 100 feet wide. The tanks are divided by brick walls. The floors are of concrete, and fall from the north to the south ends, where the decanting valves are placed. The average depth of the banks is six feet, and their total capacity is 12,375,000 gallons.

Machinery.

The machinery at Davyhulme includes the plant necessary for pressing the sludge into cake, and for liming the sewage and for re-liming any sludge which is pressed into cake, and for ejecting the sludge from the precipitation tanks to the sludge storage tanks near the jetties below Barton Locks.

Boilers.

The boilers, two in number, are of the double-flued Lancashire type, each being 30 feet long by 7 feet 6 inches diameter. The working pressure is 75 lbs. per square inch. An economiser has been erected at the back of the boilers, and space has been reserved in the boiler-house for a third boiler.

Engine-House.

The engine-house is 70 feet by 33 feet, and contains the following machinery, viz. :—

Two air compressors, with steam cylinders 14 inches diameter, air cylinders 12 inches diameter, with a 20-inch stroke. The crank shaft is furnished with double fly-wheels, the whole being mounted on cast-iron air receivers. The air-pressure for charging the sludge-presses ranges from 75 to 100 lbs. per square inch. The normal pressure is 90 lbs. These compressors are also used for supplying compressed air for working two ejectors, which force the sludge up to two storage tanks, from which it gravitates to the ship. A low-pressure air receiver is also provided. The ejectors are worked at a pressure of about 35 lbs. per square inch.

Two sets of duplex pumps are used for supplying hydraulic pressure for actuating the rams of the sludge-presses. These pumps have steam cylinders 9¼ inches diameter, and steel ram cylinders 1 inch diameter, with a 9-inch stroke. They supply the water direct to the accumulator, which has a ram 7 inches diameter, the casing being weighted

with scrap. The press rams are worked at a pressure of 27 cwts. per square inch.

The engine for driving the dynamo is of the vertical type, with cylinder 12 inches diameter by 16-inch stroke. The revolutions per minute in normal work are 150. This engine drives, by means of link leather belting, one dynamo for the lighting of the works and the approach road. Batteries have been provided for the storage of electricity.

The engine for driving the screening-chamber machinery is of the horizontal type, with double cylinders 10 inches diameter and 20-inch stroke.

A small vertical engine is used for driving the lime pug mill.

A duplicate pump, with cylinder 9 inches diameter by 10-inch stroke, was provided for supplying the lime mixers with water.

Lime-House.

The lime-house is 83 feet by 55 feet, and is divided into five bunkers, with a barrow road connecting the store with the lime-mixing room. There is a gallery 17 feet wide extending the whole length of one side of the store. The lime is tipped on the ground level, and from thence barrowed to the slaking pits.

There are six lime-mixers, with revolving horizontal arms for incorporating the slaked lime and water. These machines are placed on a raised gallery, and are fed by chain elevators and small buckets. They are utilized as a stand-by, the mixing being mainly done by a pug mill.

Sludge Steamer.

The new sludge steamer "Joseph Thompson," built by the Naval Construction and Armaments Company, of Barrow-in-Furness, arrived at the wharf below Barton Locks on the 11th December, 1897. This vessel was constructed on the same lines as the six vessels in use on the Thames for the disposal of London sludge. (*See* p. 208.)

The sludge storage tanks are situated on high ground near to the Ship Canal, below Barton Locks; and the steamer is filled from them by means of a cast-iron outlet pipe 24 inches in diameter, through which the sludge flows by force of gravitation.

Capital Cost of Works.

The total capital cost of the site of the works at Davyhulme and the expenditure in tanks and equipment, exclusive of the filter beds now being constructed, amounts to nearly £230,000.

Chemical Treatment.

The amount of lime and copperas added varies considerably according to the character of the sewage, the quantity of precipitant used for the twelve months ending March 27th, 1901, being at the average rate of—

	Grains per Gallon.
*Lime (CaO)	2·17
Sulphate of Iron	1·17
	3·34

In order to account for these apparently low numbers, it must be remembered that the character of the various trade effluents in Manchester sewage is such that they often mutually precipitate one another, and, consequently, reduce the amount of precipitant necessary.

After the first flush of a storm, moreover, the sewage is highly dilute, and it has, therefore, been customary to discontinue treatment at these times, as the effect of chemicals diminishes as the sewage becomes less concentrated.

The following table shows the results of chemical treatment for the period 1896—1902.—[*See* Table XX.]

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*Compare this with the scheme in use for the London sewage which I prepared in 1884—viz., lime 3·7 and sulphate of iron 1·0 grains per gallon. (*See* p. 209.)

TABLE XX.—*Showing Results of Chemical Treatment*, 1896—1902.

(*Chemical Results in Grains per Gallon.*)

DATE.	Oxygen Absorbed—4-Hours Test.				Oxygen Absorbed—3-Minutes Test.					AMMONIAS.							
										Free and Saline.				Albuminoid.			
	Raw Sewage.	Settled Sewage.	Tank Effluent. Average of Hourly Samples.	Tank Effluent to Filters.*	Raw Sewage.	Settled Sewage.	Tank Effluent. Average of Hourly Samples.	Tank Effluent to Filters—Before Incubator.*	Tank Effluent to Filters—After Incubator.*	Raw Sewage.	Settled Sewage.	Tank Effluent. Average of Hourly Samples.	Tank Effluent to Filters.*	Raw Sewage.	Settled Sewage.	Tank Effluent. Average of Hourly Samples.	Tank Effluent to Filters.*
1896.																	
January to March	4·76	...	...	1·83	...	...	...	...	...	1·78	...	...	1·85	·43	...	...	·223
July—September	...	2·47	...	1·41	...	...	...	...	...	...	2·30	...	1·78	...	·42	...	·20†
September 23rd—October 14th	...	2·30	...	1·01	...	...	...	...	...	...	1·19	...	1·18	...	·33	...	·15‡
October 21st—December 30th	...	2·46	2·00	...	...	...	...	...	...	...	2·10	2·04	...	...	·37	·32	...
1897.																	
January 6th—May 12th	...	3·20	2·43	2·24	...	1·31	·96	·78	1·22	...	2·01	1·89	2·06	...	·35	·30	·29
May 19th—August 25th	...	5·37	4·58	4·45	...	2·57	2·23	2·39	2·64	...	2·12	2·08	2·07	...	·32	·265	·25
September 1st—December 29th	7·60	...	4·68		3·46	...	2·40			2·21	...	2·05		·56	...	·295	
Year ending March, 1899	...	4·86	4·17	4·05	...	2·61	2·32	2·25	2·52	...	1·91	1·76	1·74	...	·305	·250	·250
Year ending March, 1900	...	4·56	4·26	4·25	...	2·50	2·34	2·28	2·98	...	1·90	1·80	1·85	...	·280	·247	·226
Quarter ending June 27th, 1900	...	5·84	5·15	5·09	...	2·89	2·70	2·70	3·29	...	2·05	1·98	1·89	...	·310	·280	·260
June 19th, 1900—March, 1901	8·24	...	4·92	...	3·97	...	2·74	2·58	2·88	1·89	...	1·86	...	·51	...	·324	...
Year ending March, 1902	8·85	...	5·35	...	4·36	...	2·95	...	...	2·20	...	2·30	...	·58	...	·34	...

* The numbers given in these columns are the average results of analyses of samples of Tank Effluent taken when filling the experimental filter beds.
† Tank Effluent sampled at 2 p.m. only each day. ‡ Tank Effluent sampled twice per day.

Sludge Disposal.

The steamer makes, on an average, rather more than three trips per week. Calculating from the number of ejector discharges and the density of the sludge, it is found that the weight of sludge removed per annum is about 195,000 tons.

Cost of Chemical Treatment.

The cost of treatment per million gallons of sewage by the precipitation method for the year ending March 27th, 1901, amounted to £1 9*s.* 8·6*d.*, apportioned as follows:—

	Per Million Gallons. £	*s.*	*d.*
Precipitation	0	7	0·6
Sludge Disposal	0	10	11
Coal	0	2	5·4
Incidental Expenses (including Professional Charges, Renewals, and Repairs, less Receipts)	0	9	3·6
	£1	9	8·6

Experiments on further Purification of the Sewage.

It is a matter of common knowledge that the system of purification by chemical treatment as above described is inadequate, owing to the fact that the effluent still contains a large amount of putrescible organic matter, thereby adding to the already considerable pollution of the Ship Canal water.

This matter has for long been the subject of complaint of the Mersey and Irwell Joint Committee, and in May, 1898, the Manchester City Council resolved to take the advice of three eminent experts—one chemical, one biological, and one engineering—on the general question.

Mr. Baldwin Latham was appointed as engineer, Professor Percy Frankland as bacteriologist, and Professor W. H. Perkin, junr., as chemist.

After considering various propositions which had been made for the treatment of the sewage, and after visiting several other towns, the experts were led to experiment on the application of bacteriological processes to the purification of Manchester sewage.

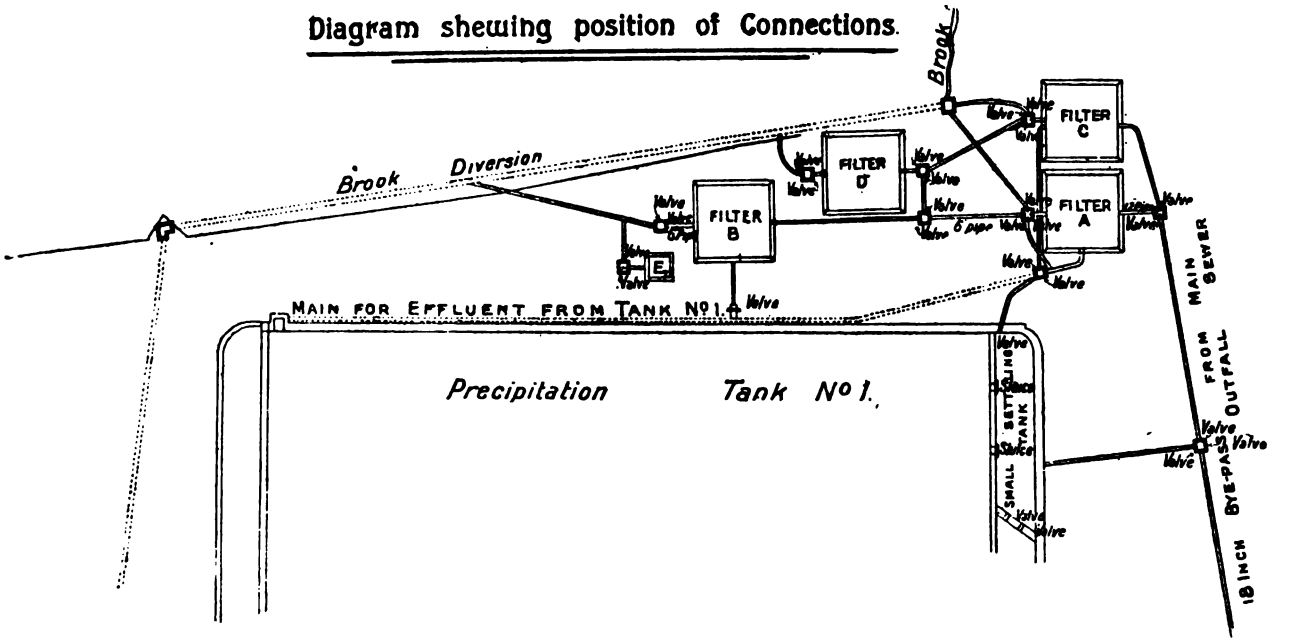
Some of the more urgent points demanding elucidation were the following:—

1. To determine whether the trade refuse in Manchester seriously impaired the efficiency of the bacteriological treatment.
2. To determine whether a portion, at any rate, of the sludge can be destroyed by bacterial agency.

Diagram G.

EXPERIMENTAL FILTERS.

Diagram shewing position of Connections.



To face page 133.]

3. To determine whether the addition of chemicals to the sewage before bacteriological treatment can be dispensed with.
4. To determine whether the aërobic (decomposition of organic matter by bacteria in presence of air) or a combination of anaërobic (similar decomposition without air) and aërobic processes is the most advantageous.

An experimental installation was laid down by which the sewage could be subjected to a great variety of conditions of treatment. These experiments were carried out under the direction of the experts to the beginning of 1900, and are still being continued by the superintendent.

A diagram showing the arrangement of the bacteria beds A, B, C, D and E is inserted. (Diagram G.)

The details of construction will be found in the various reports which have been published from time to time.

The following lines of investigation were pursued:—

The treatment of *Settled Sewage* by *single*, *double*, and *triple contact* on bacteria beds;

The treatment of *Raw Sewage* by *single*, *double*, and *triple contact* on bacteria beds;

The treatment of *Raw Sewage* by means of the *open septic tank*, followed by *one* or *more contacts* on bacteria beds;

The treatment of *Raw Sewage* by means of the *closed septic tank*, followed by *one contact* on bacteria beds;

The treatment of *Storm Water*.

In addition to the experiments carried out in connection with the installation above mentioned, experiments on the purification of *chemically-treated sewage* on bacteria beds, which had been started by Sir Henry Roscoe in 1895, were continued, and are still being carried on at the present time.

From these experiments it has been concluded—

(1) That the bacterial system is the system best adapted for the purification of the sewage of Manchester.

(2) That the bacterial processes are best conducted in several stages, viz.:—

(i) Settlement and screening out of the grosser solids.

(ii) Anaërobic decomposition in the septic tank.

(iii) Oxidation on bacteria beds.

For thoroughly satisfactory purification more than one contact is necessary for Manchester sewage; but recent experiments have shown that the area of secondary beds may be considerably less than the area of primary beds.

The following table will show the average composition of the open
it being understood that the area of the latter is only one-half that of

TABLE XXI.—*Treatment of Open Septic Tank Effluent on Beds*

Periodical Averages of Daily Samples,

DATE.	* Oxygen Absorbed, 4 hours			Free and Saline Ammonia			* Albuminoid Ammonia		
PERIOD ENDING	Tank effluent	Average filtrate from beds "A" and "C"	Filtrate from bed "D"	Tank effluent	Average filtrate from beds "A" and "C"	Filtrate from bed "D"	Tank effluent	Average filtrate from beds "A" and "C"	Filtrate from bed "D"
April 11th, 1900	5·83	2·35	·47	1·84	·90	·54	·275	·079	·035
September 12th, 1900.	5·63	1·61	·56	2·18	·67	·23	·32	·130	·056
December 26th, 1900..	6·11	1·44	·53	2·03	·63	·225	·36	·140	·06
March 27th, 1901	6·42	1·46	·45	1·94	·80	·26	·34	·105	·04
June 26th, 1901.....	5·70	1·43	·57	2·53	·86	·28	·36	·135	·06
September 25th, 1901.	5·25	1·56	·68	3·12	1·19	·39	·33	·120	·06
December 25th, 1901..	6·15	1·69	·58	3·03	1·15	·48	·32	·125	·06
March 26th, 1902	6·26	1·75	·57	2·06	·90	·45	·33	·110	·05

* Mersey and Irwell Joint Committee's Limits of Impurity:—

4 Hours Oxygen Absorption = 1 grain per gallon.

Albuminoid Ammonia = ·1 grain per gallon.

septic tank effluent and the filtrate from primary and secondary beds, the former :—

"*A*" *and* "*C*" (*Primary*) *and* "*D*" (*Secondary*).

Commencing January 4th, 1900.

Nitrous Nitrogen (in terms of NH_3)		Nitric Nitrogen (in terms of NH_3)		INCUBATOR TEST.							
				3 minutes Oxygen absorption					Putrescibility		
				Before Incubator			After Incubator				
Average filtrate from beds "A" and "C"	Filtrate from bed "D"	Average filtrate from beds "A" and "C"	Filtrate from bed "D"	Tank effluent	Average filtrate from beds "A" and "C"	Filtrate from bed "D"	Average filtrate from beds "A" and "C"	Filtrate from bed "D"	Filtrate from bed "A"	Filtrate from bed "C"	Filtrate from bed "D"
·019	·014	·275	·66	3·10	·69	·22	·62	·17	$\frac{2\ 7\frac{1}{2}}{9\ 9}$	$\frac{1\ 2\frac{1}{2}}{7\ 7}$	$\frac{0}{1\ 7\ 5}$
·036	·023	·49	1·01	3·01	·85	·25	·81	·19	$\frac{3\ 6\frac{1}{2}}{1\ 0\ 0}$	$\frac{2\ 8}{1\ 0\ 5}$	$\frac{0}{2\ 0\ 4}$
·023	·025	·68	·95	3·18	·69	·23	·54	·17	$\frac{4\frac{1}{2}}{5\ 9}$	$\frac{3\frac{1}{2}}{5\ 8}$	$\frac{0}{7\ 1}$
·030	·02	·69	·98	3·35	·73	·19	·52	·15	$\frac{2\frac{1}{2}}{5\ 9}$	$\frac{\frac{1}{2}}{5\ 8}$	$\frac{0}{7\ 6}$
·060	·03	·73	1·18	2·96	·69	·23	·45	·18	$\frac{0}{4\ 4}$	$\frac{0}{4\ 2}$	$\frac{0}{5\ 1}$
·045	·03	·88	1·32	2·87	·77	·28	·61	·24	$\frac{0}{5\ 5}$	$\frac{1\frac{1}{2}}{6\ 0}$	$\frac{0}{7\ 3}$
·025	·02	·96	1·45	3·27	·87	·26	·62	·21	$\frac{0}{6\ 6}$	$\frac{\frac{1}{2}}{6\ 6}$	$\frac{0}{7\ 2}$
·030	·01	·86	1·29	3·44	·99	·22	·64	·20	$\frac{0}{7\ 3}$	$\frac{0}{7\ 6}$	$\frac{0}{7\ 6}$

The following paragraphs embody some of the more detailed conclusions which have been reached:—

The Work of the Septic Tank.

(i) The effluents from closed and open septic tanks are practically identical in composition.

(ii) With a tank space equal to half the daily flow of Manchester sewage, it is possible to digest about 25 per cent. of the total suspended matter in the sewage.

(iii) The suspended matter in the septic tank effluent is of a granular character, and readily separates out on standing, and when arrested on the surface of a bacteria bed does not seriously impede the free flow of the water into the bed.

(iv) The organic matter in solution is much more easily nitrified than that present in fresh sewage, so that it is possible with one contact to constantly obtain non-putrefactive filtrates.

(v) The blending which takes place in the septic tank is of value in minimising the effect of excessive amounts of manufacturing refuse, and in producing an effluent of fairly constant composition.

Capacity of Contact Beds.

The capacity of contact beds suffers a rapid initial decrease; but afterwards, with careful working, the rate of decrease is very much less.

As the question of capacity and the maintenance of the beds is of considerable importance, the conclusions with regard to these points may be given more fully.

Causes of loss of Capacity of Contact Beds.

From the experience gained with beds A, B, C and D, and also with the other experimental beds reported upon, it has been concluded that the chief causes of loss of capacity are the following:—

(a) Settling together of the material.
(b) Growth of organisms.
(c) Impaired drainage.
(d) Insoluble matter entering bed.
(e) Breaking down of material.

(a) *Settling together of material.*—This must always occur, and largely accounts for the initial rapid decrease in capacity. It may be well, at

the outset, to place the material in the bed to a slightly greater depth than that actually required, so as to allow for this settlement.

(b) *Growth of organisms.*—This is at once the cause of increased efficiency in the bed, and of loss of capacity. On examining the material of a contact bed in active condition, every piece is seen to be coated over with a slimy growth. If this is removed it soon dries to a stiff jelly, which can be cut with a knife. Under the microscope, masses of bacteria and zoogloea will be found to be present. If placed in a tube containing air, and connected with a manometer, the jelly will rapidly absorb all the oxygen, and produce carbon dioxide.

This action will sometimes produce a vacuum of several inches of mercury. There is little need, therefore, to force air into a bed, as the natural interchange of gases which takes place is sufficient for adequate aeration. As a matter of fact, there is always a large amount of oxygen to be found at the bottom of a bed in good condition. The behaviour of the bacterial jelly appears to afford the clue to the successful working of bacteria beds. By working them at a high speed—*i.e.*, filling them frequently in the day without long periods of rest—the effluent may remain good, but the bacterial growth so rapidly increases that the bed becomes too spongy, and will not allow the water to drain away. Here, too, is the explanation of the fact that, within limits, decrease of capacity is accompanied by increase of efficiency.

This decrease of capacity may, however, become so great as to outweigh the advantage of increased efficiency. A long period, say one or two weeks rest, must then be given to the bed.

The superfluous bacterial growths will during this time be rapidly consumed, and the capacity of the bed will greatly increase. These rests should not exceed a fortnight at most, as the bed then tends to dry up, and the activity of the organisms diminishes.

It is, therefore, important that the decrease of capacity should not be allowed to become excessive before resting, or it may not be possible to completely recover the loss during the time of rest.

In the case of the beds A, B, and C, before the best conditions of working had been ascertained, the capacity had been allowed to decrease to an undesirable extent.

(c) *Impaired drainage.*—Defective drainage decreases the actual water capacity of the beds, and prevents thorough aëration, and every means should be taken, therefore, to make it as perfect as possible.

(d) *Insoluble matter entering bed.*—The effect of insoluble matter in decreasing capacity depends on its nature. If sandy in character its effect will be small, as the sand itself has a water-holding capacity.

In Manchester the chief insoluble matters entering the beds are finely divided clay (especially in wet weather) and compounds of iron. Most of the iron in the septic tank effluent is in suspension as sulphide. This can largely be retained on the surface of the bed. The small amount of iron which is deposited from solution can affect the capacity only very gradually. As a matter of fact, most of the insoluble matter passing on to the beds appears to be in the top six inches, and if the cinders below this are left undisturbed, a fairly sharp line can be distinguished between the surface layer and the cinders. The fact that no permanent loss of capacity has occurred over fifteen months shows that most of the insoluble matter must have remained on the surface of the bed, and such as has entered must itself possess a water capacity.

Evidently, then, it is of importance to retain insoluble matter as far as possible on the surface. This may be done by making the upper layer of rather finer material than the body of the bed. Experiments are in progress to determine whether, in course of time, this upper layer can be used after removal for growing vegetables, as it has been found to contain large quantities of nitrates and some phosphoric acid.

(e) *Breaking down of material.*—Little, if any, evidence of this is present in the beds under discussion. Its occurrence would be a more serious cause of loss of capacity than any of the foregoing, and should be avoided by using only hard refractory material.

Conditions of Successful Working of Contact Beds.

In view of the observations above recorded, the following method of procedure is recommended for the successful working of contact beds:—

(i) The bed should be worked very slowly at first, in order to allow it to settle down, and the bacterial growths to form. In this way there will be less danger of suspended matter finding its way into the body of the bed, while the material is still loose and open.

(ii) The burden should not be increased till analysis reveals the presence of surplus oxygen, either dissolved, or in the form of nitrates in the effluent.

(iii) Analyses of the air in the bed may usefully be made from time to time during resting periods.

(iv) The variations in capacity should be carefully recorded. If the capacity is found to be rapidly decreasing, a period of rest should be allowed.

(v) Long periods of rest should be avoided during winter, as when deprived of the heat of the sewage the activity of the organisms decreases. If necessary, the burden on the bed should then be decreased by reducing the number of fillings per day, rather than by giving a long rest at one time.

(vi) The insoluble suspended matter should be retained on the surface by covering, at any rate, a portion of the latter with a layer of finer material, not more than three inches in depth. The suspended matter thus arrested should not be raked into the bed, but when its amount becomes excessive it should be scraped off. This should be done if possible in dry, warm weather, after the bed has rested some days. By placing the inlet and outlet penstocks as close together as possible, the suspended matter will tend to concentrate in their vicinity, and its removal will be facilitated.

The Treatment of Storm Water.

It has been concluded that special provision must be made for the treatment of storm water, especially of the first flush. The special area of beds laid out for the treatment of storm water must be lightly worked during dry weather, so that they may be stored with nitrates, and thus be in a condition to be worked at an accelerated rate for a short time. In this manner the first flush can be dealt with. Afterwards, when the sewage has become highly dilute, it may be purified by settlement, followed by continuous filtration through the storm beds.

This matter will be further referred to when the construction of the storm beds is described.

The Bacterial Treatment of Manchester Sewage on the Working Scale.

Open Septic Tank and Contact Beds.

For the purpose of testing the behaviour of beds with septic tank effluent on the working scale before laying down a large area, two half-acre beds were constructed and brought into work at the beginning of 1901. These are distinguished as 1A and 2A. Since this time ten more half-acre beds have been brought into operation.

The results obtained by the treatment of open septic tank effluent on

bed 1A, which has been longest in operation, are summarised in the following table:—

TABLE XXII.—*Table showing Average Results from Bed 1a from week ending January 30th, 1901, to week ending March 26th, 1902.*

(*Results in Grains per Gallon.*)

Oxygen Absorbed, 4 hours.		Albuminoid Ammonia		Nitric Nitrogen (as N H_3)		Incubator Test. 3 minutes Oxygen Absorption.			
						Before Incubator		After Incubator	
Open Septic Tank Effluent	Filtrate from Bed 1A	Open Septic Tank Effluent	Filtrate from Bed 1A	Open Septic Tank Effluent	Filtrate from Bed 1A	Open Septic Tank Effluent	Filtrate from Bed 1A	Open Septic Tank Effluent	Filtrate from Bed 1A
6·33	1·93	·32	·11	Nil	·37	3·44	1·15	Not determined	·91

The majority of samples have been non-putrefactive, exceptions occurring at times when the sewage contains excessive amounts of dissolved impurity.

The amount of effluent dealt with on the beds has been gradually increased. At present the beds which have been longest at work are receiving open septic tank effluent at a rate equivalent to upwards of 400,000 gallons per acre per day.

In judging of the number of fillings per day which could be taken by a bed, two things have been borne in mind, viz., the capacity of the bed and the quality of the filtrate.

The tank effluent is distributed on to the bed by means of radial grips lined with screenings from the main bulk of the clinkers. In this way most of the suspended matter in the tank effluent is retained in the grips, and can be readily scraped off from time to time.

Measurements of *capacity* have been made from time to time by means of a suitable form of meter placed in the pick-up channel, so as to measure the volume of the discharge; and this method of measurement is now in process of further application by means of a similar meter placed in the supply channel, which will admit of a similar measurement of the water admitted to the beds, the arrangement being designed in such a way that each meter will be available for two beds. In this way the volume of supply can be tested for accuracy against the corresponding discharge.

It has been found that after 402 fillings, bed 1A has a capacity of 166,000 gallons, or 36·6 per cent. of its empty capacity, after 159 fillings; Bed 1 has a capacity of 178,550 gallons, or 39·4 per cent. of its empty capacity.

Treatment of the Effluent from Chemical Precipitation on the Storm Beds.

Quite recently it has been customary once a day to fill such storm beds as are completed with the effluent from chemical treatment.

A very fair filtrate is obtained, and thus the amount of sewage purified pending the completion of the works is increased, and at the same time the storm beds are kept in an active condition.

New Works.

The general arrangement of the new works now contemplated and being carried out in accordance with the resolution of the City Council of the 5th September, 1900, under the sanction of the Local Government Board, comprise the following:—

1. Five additional tanks, with contingent works, similar to the existing precipitation tanks at Davyhulme.
2. Forty-six acres (net) first contact bacteria beds, in 92 beds of half an acre each, at Davyhulme.
3. Twenty-six acres storm-water filter beds, also at Davyhulme.
4. Conduit for conveyance of first contact effluent from Davyhulme to beds and land at Flixton.
5. Forty-six acres (net) second contact bacteria beds on land in the township of Flixton.
6. Works of irrigation in Flixton and Carrington, covering approximately an area of 100 acres.

The scheme under which these works are being carried out has been designed to deal with a maximum rate of flow equal to 126 million gallons per 24 hours, the flow up to 63 million gallons being treated by double contact on the bacteria beds, and the subsequent 63 million gallons on the 26 acres of storm-water filter beds.

The excess of the sewage flow in time of rain, beyond the maximum rate, will be passed off into the Manchester Ship Canal at the Mode Wheel storm-water overflow.

Screening.

The present screening chambers, which are in duplicate, as previously described, and have for some time past been performing their work in satisfactory manner, will remain intact, and will be continued in use as at present.

Tanks.

The number of tanks at present existing is 11, of which six are on the north side and five on the south side of the central roadway. Each of these is 300 feet in length, 100 feet in width, with an average depth of 6 feet, containing a volume of 1,125,000 gallons.

Four of these existing tanks, viz., two on each side of the centre roadway, will be set aside as detritus tanks for storm water, which will be delivered to the new storm-water filters by means of the present 16-feet carrier to be reserved solely for that purpose.

In substitution for the four tanks set apart in connection with storm water, five new tanks will be provided, viz., two at the north end and three at the south end of the present range. This will render the whole series north and south equal and symmetrical.

The effluent cills of the seven existing tanks now to be utilized as septic tanks are being raised to the extent of 14½ in., thus affording an increased water capacity and additional fall. The cills of the new tanks will be finished at the same level.

With these modifications and extensions, the water capacity of the septic tanks will be 15,820,500 gallons, giving with the four storm-water tanks (which may probably be used for night flow) a total capacity of 20,320,500 gallons.

Bacteria Beds.

Davyhulme.

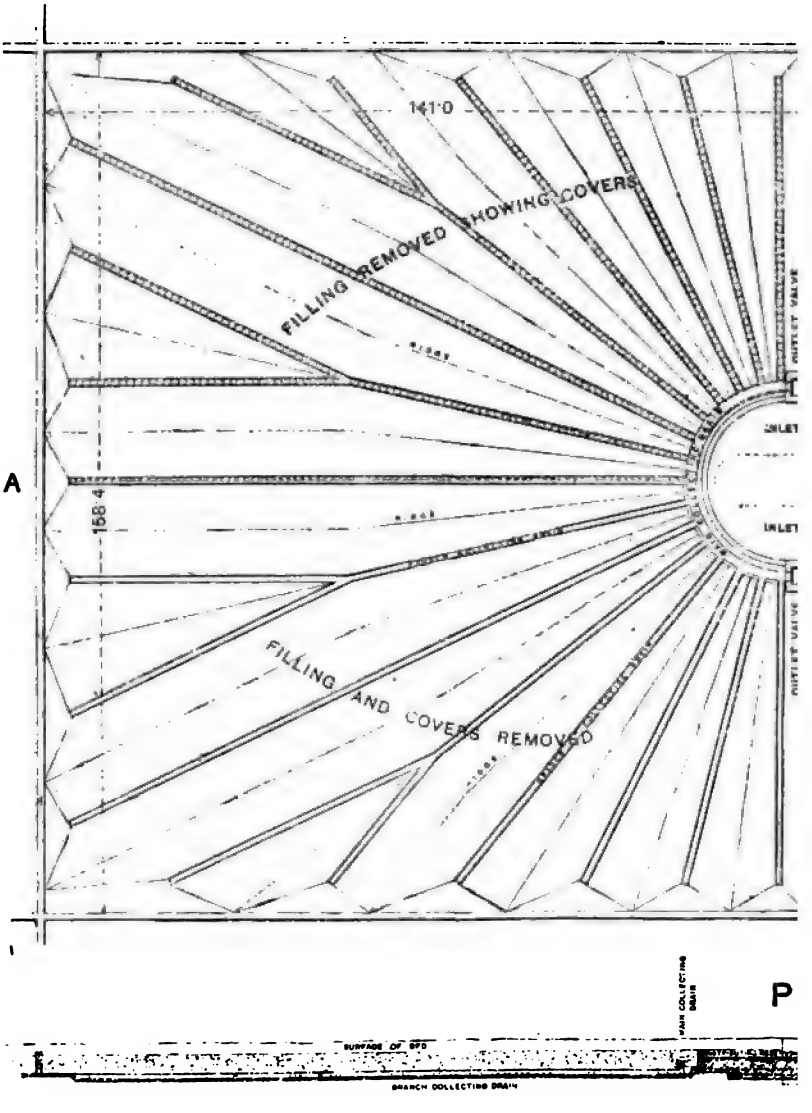
The number of first contact beds provided for at Davyhulme is 92, each being a net half-acre in area, and covering in all 46 acres.

They are disposed on the land in three blocks or series, containing respectively as follows:—

Series I.	.....	20 acres.
,, II.	.....	6 ,,
,, III. and IIIA.	.....	20 ,,
		46

Series I. and II. are supplied from the northerly, and III. and IIIA. from the southerly range of septic tanks.

Diag



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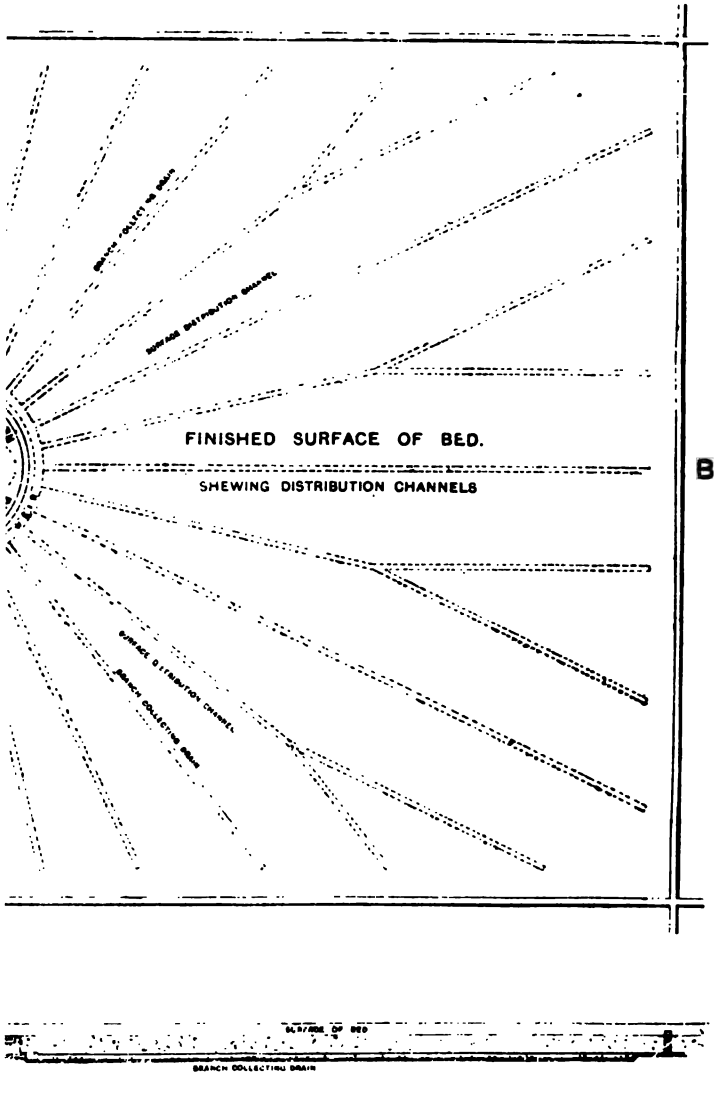

[*To face p.* 143.

Each series will be served by main supply channels, 18 ft. and 16 ft. wide, with subsidiary channels, 6 ft. and 5 ft. wide, as required in the several cases.

The latter are constructed with draw-off or pick-up channels of the same width below (as shown by drawings), for economy of area and construction.

The scheme of bacteria beds has been laid out as far as possible on broad and simple lines, so as to promote ease and facility of working.

The beds are, with few exceptions in each series, of uniform shape and dimensions, and the point of admission of sewage to each bed is in the centre of the longer side adjoining the supply channel, which serves as a rule an equal range of beds on either side, so that in general the distributing centres fall in pairs opposite each other.

Supply channels are of adequate width and gradient to permit of delivering the volume of sewage necessary for filling two beds at once on the same channel in the minimum required time by gravitation to each distributing centre in the scheme.

A reference to the detail drawing (H) will show that the supply to and discharge from each bed are radial, delivering from one centre outwards over the surface, and converging towards the same centre by the under-drainage below. The sewage is admitted from the supply channel to a distributing reservoir, from which it flows over a cill or weir of circular form, and thence along channels cut in radiating form over the surface of the bacteria bed. These channels are lined with fine grade material, which tends to arrest suspended matters on its surface, and retain them from entering into the body of the bed.

The under-drainage of each bed is also laid out in radial form, the drainage lines converging into a main collecting drain, which is concentric with the distributing weir, and which communicates at each end with manholes, or at the centre with an outlet well, from which the discharges enter the draw-off channel.

The under-drains are channels formed in the concrete bottom of the bed, covered with stoneware perforated slabs, set in rebates, so as to be flush with the surface of the bottom.

The average depth of the clinkers forming the body of the bacteria beds is 3 ft. 4 in., each bed having a cross fall of 2½ in., and the space between the radial drainage lines being formed with a ridge in the centre to facilitate the discharge of the final drainage at the bottom.

The body of the bacteria beds is composed of furnace clinkers from which the fine material has been removed by screening, and the coarsest material is used for covering more particularly the radial drainage lines, and also the concrete bottom as far as practicable.

Storm-Water Filter Beds.

These beds have been designed to deal with a maximum quantity of 63 million gallons per 24 hours, at a rate not exceeding 500 gallons per square yard per day, and consequently cover an area of about 26 acres. (*See* Diagram I.)

The general area of each filter bed is about one acre, and the beds are 2 ft. 6 in. deep, being filled with unscreened clinkers, the coarser part of the material being selected for the covering of the under-drains and the surface of the bottom.

These beds are at present being used as contact beds for the purification of chemical tank effluent, or for the treatment of storm water by continuous filtration. In the former case, the bed is filled and discharged in a manner similar to that in use on the bacteria beds proper; and in the latter case, provision is made, by the method shown on the drawings, for the ponding of the liquid upon the surface to a depth of about 6 in., at which depth delivery commences over a bell-mouth pipe in the outlet well, continuing during the progress of the storm, the body of water in the bed being drawn off after the rain has ceased.

Under the latter conditions of working, each acre of storm filter will receive about 363,000 gallons before discharge commences, and 26 acres will then be adequate for the reception of about 9½ million gallons before commencing to flow off, after which the rate of discharge would be about 500 gallons per square yard, or 2,420,000 gallons per acre per day. The storm-water tanks and filters together will thus provide for the storage of a volume of 14,000,000 gallons in time of storm before discharge begins, covering a period of at least five hours' heavy rain, exclusive of the volume treated in bacteria beds.

The storm-water filter beds are supplied by channels varying from 10 ft. to 4 ft. in width, having a general gradient of 1 in 1,000, with their draw-off channels below. In general, as shown by the drainage, there are two points of supply to each acre of area to which the under-drainage also is conducted.

The floor of these beds is the natural ground surface,* which is generally a clayey marl, covered with a layer of cement concrete where the character of the ground renders it necessary.

The smaller under-drains are of brick, laid with open joints on a concrete foundation, and covered with open-jointed stoneware or fire-clay slabs, cemented down, the main collecting drains being close jointed.

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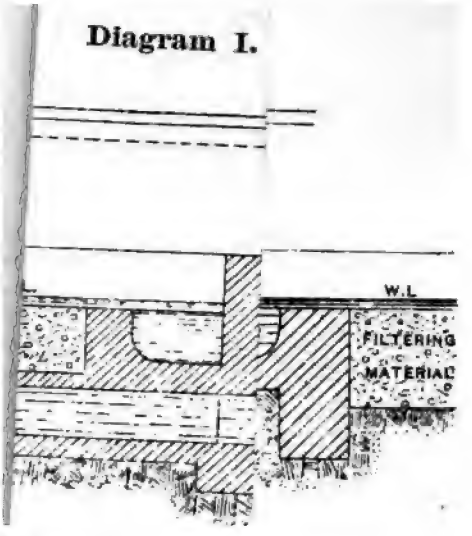
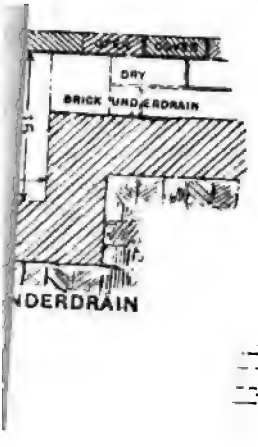
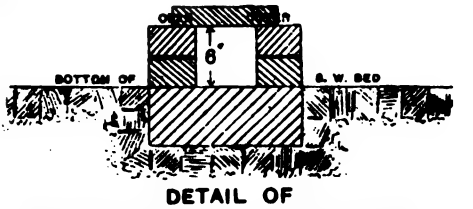
* As in the case of the original one-acre bed at Barking Creek, and those at Sutton.

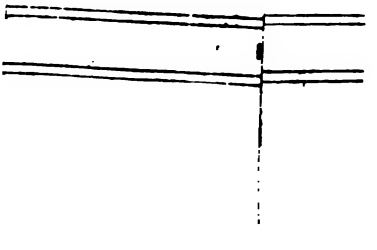
Diagram I.







DETAIL OF
BRANCH DRY BRICK UNDERDRAIN



side of the river. They will form a compact range, four beds in width and twenty-three beds in length, with supply channel on the upper or north side, and effluent discharge channel on the south side. The beds will be separated by distributing channels, with pick-up or draw-off channels below, and cross roadways between, as at Davyhulme. The method of supply and distribution is precisely the same as before described.

The forty beds nearest to the inlet end have a separate effluent channel, communicating by a carrier with the land on the Carrington side of the river, sixty-four acres of which it is proposed to lay out with shallow under-drainage for irrigation purposes.

Thirty-six acres on the Flixton side of the river are also available for the same purpose, together with the sixty-four acres, making a total of about one hundred acres available for irrigation.

The syphon carrying effluent water from the bacteria beds would consist of a tunnel under the river, 5 ft. diameter, with shaft at each end, that on the Carrington side communicating with a supply channel, 13 ft. wide, following the contour of the high land, from which the effluent would radiate over the land in subsidiary carriers, 18 in. wide, with disc valves on the upper ends in the carrier wall, so that any length could be opened or shut off at will.

The main drains would lie midway between these carriers, communicating with an open channel delivering into the Ship Canal over a tumbling bay, placed sufficiently far back from the canal bank to minimise any current prejudicial to navigation.

The under-drainage would be of agricultural drain pipes, 3 in. diameter, laid out in herring-bone form, and at an average depth of 2 ft.

Land at Carrington and Flixton.

The gross area of the land for which compulsory powers of acquisition have been obtained is 204½ acres, exclusive of river bed, in addition to which small areas amounting to 2½ acres are suitable for acquisition to straighten the boundary, making a total area of 207 acres.

Materials and Manner of Construction.

Additional Tanks, &c.

For the enclosing walls and division walls of additional tanks and carriers, and the submerged walls of the present and new tanks, the material will be common brick in cement mortar, faced with blue brick on both sides to the underside of the copings.

The copings of tanks and carrier walls will be of hard Yorkshire stone, to harmonise with present work. The submerged walls will be finished with a coping of blue brick on edge, in cement, with bull-nosed angles.

The bottoms of the new tanks will be of Portland cement concrete.

Bacteria Beds and Storm-Water Filter Beds.

Distributing and Pick-up Channels, &c.

The work in all pick-up or draw-off channels and division walls is of Portland cement concrete, the tops being finished in the same material throughout.

The concrete work will be the predominant feature in the construction of the works, and materials for it can be procured at a price which, even if brought from a distance, compare favourably with the price at which they can be procured in the immediate neighbourhood.

Irrigation Areas.

Flixton and Carrington.

The under-drains would be of 3-in. agricultural tiles, with master drains of glazed butt-jointed pipes, 18 in., 15 in., 12 in., and 9 in. diameter. The smaller carriers to be of 18 in. half-socketed glazed pipes, with earthwork banks.

Operation of Sluices.

Bacteria Beds.

The systematic opening and closing of the inlet and outlet sluices or penstocks, in accordance with a generally normal cycle, is a matter of great importance, and specially so in connection with the bacteria beds.

Pending the selection of a suitable form of apparatus, hand valves are being employed for this purpose.

Sluices on Storm-water Filters, &c.

The method of management on these beds will be to leave a proportion of the inlet sluices under normal working always open, with the corresponding outlets closed.

Excess of rain would therefore always find filter beds with their sluices open to receive it at any time, in which it could fill and pond up till the requisite level is reached, when it would deliver automatically into the outlet channels. The first downpour of rain would thus be provided for, by which time if further openings were required they could easily be provided.

Similarly, the larger isolated sluices are intended to be opened and closed by manual labour.

Estimated Cost.

The total estimated cost of the new works as above described is £487,283 17*s.* 4*d.*

The following particulars taken from the Annual Report of the Rivers Department for the year ending March 25th, 1903, will serve to show the progress of the work.

During the year, 728,000,000 gallons were passed through the septic tanks and primary bacteria beds, and 649,000,000 gallons of effluent from chemical treatment, or of settled storm-water passed on to the storm-beds.

The purification effected may be seen from the following quarterly returns, which clearly indicate the improved results obtained as the beds become matured.

IA.

3,

DATE.		Incubator Tests.			
		3 Minutes' Oxygen Absorption			Putrescibility
	Oxygen 4 [illegible]3)	Before Incubator		After Incubator	
	Tank Effluent	Tank Effluent	Bed 1a	Bed 1a	Bed 1a
Average	5·97	3·26	1·37	1·46	$\frac{67\frac{1}{2}}{120}$
Average	5·58	3·19	1·31	1·36	$\frac{59\frac{1}{2}}{125}$
Average	6·25	3·70	1·36	1·26	$\frac{24}{125}$
Average	5·87	3·28	1·15	·92	$\frac{5}{116}$

DATE.	Incubator Test.								
	3 Minutes' Oxygen Absorption							Putrescibility	
	Oxygen 4		Before Incubator			After Incubator			
	Tank Effluent	1—6	Tank Effluent	Storm Beds 7—15	Storm Beds 1—6	Storm Beds 7—15	Storm Beds 1—6	Storm Beds 7—15	Storm Beds 1—6
Average	5·13		2·81	1·01	..	·87	..	$\frac{10}{72}$	..
Average	5·21	·1	3·06	·93	1·61	·73	1·68	$\frac{1}{84}$	$\frac{7}{25}$
Average	4·79	·6	2·73	·56	·85	·39	·68	$\frac{1\frac{1}{2}}{90}$	$\frac{6\frac{1}{2}}{93}$

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CHAPTER IX.

LEEDS EXPERIMENTS.

THE following particulars of the experiments on the bacterial treatment of the Leeds sewage are from reports by Col. Harding, Chairman of the Sewerage Committee, having charge of the experiments, and at one time Lord Mayor of Leeds, Mr. T. Hewson, M. Inst. C.E., City engineer, and Mr. W. H. Harrison, M.Sc., the Chemist of the Sewage Works. It is of interest to note that Col. Harding, in addition to filling the above posts, is also a member of the West Riding of Yorkshire Rivers Board, and a member of the Royal Commission on Sewage Disposal. The first report is dated December, 1898; and the second report, July, 1900.

The city of Leeds contains, within an area of 21,572 acres, an estimated population at the present time of 416,618. Practically the whole of the city is in one sewerage system, the outfall being at Knostrop, 2½ miles from the Town Hall. The system is that known as the combined, there being no separate drains for surface water. Some 254,137 of the population drain into the sewers, the privies being used by 162,481. Most of the trade-refuse liquors go into the sewers, and comprise those from tanneries, wool scouring and dyeing, copper and galvanising works. The water supply is good and very soft; of the fifteen million gallons daily, some four millions are supplied for trade purposes. The rate of flow of the sewage rises to over twenty-two million gallons in the day, and falls to below eight million gallons in the night. One-twentieth of an inch of rain per hour will increase the flow to a rate of sixty million gallons per twenty-four hours, which is the maximum capacity of the outfall sewer.

With a view to effecting an alteration of a permanent character, the corporation have had several schemes under contemplation. One was a pumping scheme to deliver the sewage on to land near the present works, the cost of pumping alone being estimated at £11,000 per

annum, representing a capital charge of £300,000; but the land was quite unsuitable. Another was a gravitation scheme to land about 13½ miles from Knostrop. On examination, however, it was found that half the area proposed was subject to floods, and the other half unsuitable. In addition, legal difficulties were in the way. On going further afield, some 20 miles away, land was found, but the cost of the sewer would be some £400,000, which, added to the cost of the 5,000 or 6,000 acres of land, made a total of a million sterling. This being financially impossible other lands were examined, these, though 3 miles nearer than the last named, were too small, unsuitable, and beset as before with legal difficulties as to statutory rights.

Broad irrigation being found so difficult, chemical precipitation, sludge pressing and effluent irrigation in limited areas of land were considered. It was found that the cost of this, plus the capitalised cost of treatment at the tanks and pumping would be about £750,000, an amount which very easily could be largely increased by the use of the very best instead of mediocre precipitants, whilst the result would be poor for such a large expenditure.

In July, 1897, the Corporation decided to make a series of experiments as to the possibility of treating the sewage by the bacterial system. The result of the preliminary trials were satisfactory so far as the resulting effluents were concerned, but the warning which had been given as to the possible interfering action of the large quantities of iron salts in the sewage was found to be justified.

The iron liquor by itself was found to exert a sterilizing action, but when diluted with domestic sewage the bacterial action, though to some extent checked, was not stopped; but purification did not proceed with its usual ease, oxygen being absorbed by the iron salts, and was to that extent not available for oxidising the organic matter.

With samples of average Leeds sewage containing iron liquor, tan refuse, and other trade effluents diluted with domestic sewage, good results were obtained on the small experimental beds, giving 80 per cent. of purification as the measure of the work of the double beds on the matters in solution, those in suspension being entirely removed.

For the purpose of testing the process on a working scale, two of the old precipitation tanks, Nos. 11 and 12, were used. No. 11 was raised 1 ft. 6 in. for the fine bed, and No. 12 was raised 8 ft. 8 in. by filling up the bottom and raising the walls so as to form a coarse bed at such level that its contents could be emptied on to the fine bed.

The coarse bed was filled with coarse coke not less than 3 in. diameter, and the fine bed with coke not less than $\frac{3}{8}$ in. diameter and not more than $1\frac{1}{2}$ in. diameter. The floors of the beds were paved with old bricks, grouted in cement, and were formed with a fall to the outlet end of the beds. Upon these were laid 3-in. agricultural tile drains 2 ft. apart, connected at their low ends with a brick collecting drain, conveying the drainage to the outlet valves. In both rough and fine beds these drains were surrounded with specially large pieces of coke.

The size of the coarse bed is at top 90 ft. by 65 ft., and at bottom 88 ft. by 63 ft., and the depth 5 ft. The size of the fine bed is 100 ft. by 61 ft. at top, and 99 ft. by 51 ft. at bottom, and the depth is 6 ft. The average area of each bed is about 620 square yards, or, roughly, one-eighth of an acre.

The charges of the beds were measured by an iron tank, having an effective capacity of 13,187 gallons, and which was graduated. The sewage was first turned on to the beds on 2nd October, 1897. Absolutely crude sewage was used, the only matters kept back being those retained by the iron grating in the screening chamber on the main intercepting sewer, which iron grating consists of vertical bars with 1-in. spaces, and the beds were worked in this way for four months till 2nd February, 1898.

From 2nd October to December, 1897, the beds received two charges per day, but from that date, arrangements having been made to fill and empty the beds more quickly, they received three charges in the twenty-four hours until 2nd February, 1898. In the whole period from 2nd October to 2nd February the beds received 284 charges of crude sewage.

The amount of purification shown by the final effluent, after the beds had become established, proves that, notwithstanding iron liquor and other trade effluents mixed with the sewage of Leeds, it can be treated on bacteria beds so as to produce a really good effluent. Suffice it to say here, continues the report, that, taking the oxygen absorbed in four hours and the albuminoid ammonia present as measures of the work done by the beds, the figures show for the average over the whole period 73·6 per cent. of purification in regard to the latter, and 82·3 per cent. of purification in regard to the former.

The effluents from the fine bed had no smell, except at times a slight earthy odour. The first flow from the fine bed was always cloudy, and in some cases turbid, but it cleared more or less soon according to the varieties of sewage being treated; the latter part of the flow was always very clear. The average samples were for the first month cloudy, later opalescent, and in December and January almost clear when drawn off. On being kept they always cleared within twenty-

four hours, but the clearing was coincident with a deposit in the bottles of a reddish-brown flocculent matter, which on examination proved to be largely oxide of iron. This, as the effluent comes off, is in solution in the ferrous state, absorbs oxygen and precipitates as hydrated ferric oxide. The deposit is due to the large quantity of iron liquor which comes down with the sewage, and is not objectionable from a sanitary point of view. To remove this deposit by sand filtration would be quite possible, but costly.

In order to make a physiological test of the effluent, arrangements were made for the final effluent to remain in the effluent basin to a depth of about 18 in., and on 30th November, 1897, some carp were put in the basin. At first some died by the rush of the effluent carrying them against the outflow grating. Provision was accordingly made to protect the fish, and all the fish which were living at the time this was done survived, being still alive at the present time, having been continuously in the effluents, good and bad, which have passed through the basin for over a year. Green confervoid growths, generally looked upon as a sign of effective oxygenation, soon began to appear. No sewage fungus has been found about the basin.

The beds having thus given good results, there remained to consider whether the beds were really digesting the large quantity of suspended matter brought down in the sewage, or whether this was accumulating in the beds.

The next question to be determined, after ascertaining the essential fact that the bacterial process as developed at Sutton is capable of purifying the sewage of Leeds, was the rate at which the suspended matters in the sewage was being digested on the beds. "The gross capacity of the coarse bed is 174,800 gallons. The net or liquid capacity, after filling in the coke, is estimated at 83,300 gallons." From time to time careful measures were made of the water capacity. According to the results of working at Sutton for twelve months on a bed 3 ft. 6 in. deep, this factor remained practically constant; but when the beds were increased to 5 ft. 3 in. deep the liquid capacity rapidly decreased. At Leeds the following results were obtained on 5-ft. beds. Liquid capacity at the commencement: on 2nd October, 1897, 83,300 gallons; on 16th December, 1897, 58,800; on 30th December, 1897, 57,100; on 13th January, 1898, 51,100; and on 27th January, 1898, 45,400.

On 2nd February, 1898, the bed was given a rest, as the digestion of the sewage was evidently not keeping pace with the daily increment. "No doubt the reduction in capacity was also due to some extent to the settling of the coke, evidenced by the necessity for placing additional coke on the bed to raise it to its original level, and to some extent also to the grit or mineral matter which passed on to the bed,

and which it is essential to keep out, as bacterial action cannot reduce it."

In consequence of the large quantity of fibre contained in the sewage forming a sort of felted mass on the surface of the bed straining screens were provided, and a short experiment was made in the interval with the effluent from the lime precipitation. These were eminently satisfactory, in the same way as they had been with the original fine bed at Barking on the precipitated London sewage. "The experiment with screened sewage was begun on 4th March, 1898. A screen of perforated zinc with ⅛-in. holes was fixed to the top edges of the main carrier, so as to form a shallow horizontal perforated trough or gutter 3 ft. wide, about 12 in. deep, and some 40 ft. long. On starting filling, the crude sewage flowing along the gutter rapidly fell through the perforations in a fine rain, the stream reaching only a few feet forward. Paper and other solids were washed forward to the edge of the flow, and the arrangement might have proved automatic but for the large quantity of wool fibre brought down in the sewage, which gradually choked the perforations at the entrance of the gutter, and caused the flow to extend along the trough. By the occasional use of a brush, however, the attendant was able to clear the perforations and keep the flow under control." This can easily be made automatic when designing the complete works.

"The screening was found to be very effective, paper, vegetable matter, and fibre being kept back. Although the quantity appeared to be bulky, on careful measurement it only amounted to 2½ cub. ft. per day, or about 14 gallons per filling in the day, and only about 3 gallons in the night. The screenings when dry could be easily burned; and no difficulty was found as to storage, for gardeners were glad to fetch them away for use in garden frames."

The measurements of capacity were now resumed. Two days before resuming the experiment the measured capacity on 2nd March was 52,100 gallons; 14th March, 52,300; 26th March, 46,100; 9th April, 42,900; 23rd April, 40,100. On 27th April the beds were given seven days' rest. On 5th May the capacity was 45,800 gallons.

The beds had been filled three times a day since 16th December, and the change was now made to two fillings a day.

On 20th May the capacity was 44,300 gallons; 2nd June, 44,600; 16th June, 43,200.

"On 16th June the work was suspended for thirty-eight days until 25th July, because it became necessary to build a large culvert alongside the beds, and in connection with the new settling tanks."

On 28th July, 1898, the capacity was 56,500 gallons, against 57,100 on 30th December, 1897; 25th August, 1898, 43,400; 8th September, 41,100.

"In order to prevent grit from reaching the beds in future, it was now decided to alter the experiments, so that work by the beds should be preceded by a partial settling as well as the screening.

"The experiment with screened sewage had been carried on for six months, from 4th March to 8th September, with seven days' rest from 27th April to 4th May, and an enforced rest of thirty-eight days from 16th June to 25th July; in all, forty-five days, or 1½ months' rest. There had been three fillings per twenty-four hours from 4th March to 5th May, and two fillings a day from that date to 8th September.

"The number of fillings during the whole period was 315. The average of the fillings was 46,000 gallons; and the total passed on the bed during the six months was 14,490,000 gallons, against 18,346,400 from 2nd October, 1897, to 2nd February, 1898. After making allowance for the solids screened off, it is estimated that about 51,100 gallons of sludge were retained by the rough bed.

"The capacity on 2nd March was 52,100 gallons, and on 8th September 41,000 gallons; loss, 11,100 gallons.

"Deducting this from the estimated amount of 51,100 gallons retained by the coarse bed, we have 40,000, or about 80 per cent., as the amount of sludge consumed in this period by the coarse bed. The fine bed retained 16,700 gallons of sludge, the whole of which was consumed, the capacity of the bed not having been decreased. The total consumption by the two beds was 56,700 gallons of sludge," the effluents continuing to be satisfactory.

"It was then decided to experiment for four weeks with sewage settled one hour. This was begun on 9th September, the capacity of the rough bed on 8th September being 41,000 gallons; on 22nd September the capacity had increased to 47,000 gallons; on 6th October it was 46,100 gallons.

"From the large quantity of sludge left in the settling tank it was evident that the bed had too little to do as regards matter in suspension, there being only 12 grains per gallon in suspension, against 37 grains in the crude sewage.

"The sewage was therefore settled for only half an hour. On 8th October the capacity was 46,100 gallons; on 20th October, 44,900; on 3rd November, 44,100. Too much sludge was still left in the settling tank, and from 4th November the sewage was pumped on to the beds immediately after the tank was filled, when the sewage passing on to the bed was found to contain 25 grains per gallon.

"On 17th November the capacity was 42,200 gallons."

As the capacity on 9th April was 42,900, *it will be seen that not only was the digestion equal to the whole of the matter put on the bed in over seven months, but that some of the "stock," as it may be called, was reduced. On 27th January, nearly ten months previous to 17th November,*

the capacity was 45,400 gallons, so that the average daily destruction of the sludge was nearly equal to the daily supply during that period.

"Taking the year's working from 2nd October, 1897, to 1st October, 1898, there were passed over the beds in that period 683 fillings, of an average of 54,000 gallons, or in all 36·8 million gallons, and this, divided by 365 days, gives 100,000 gallons a day, including the periods of rest, forty-five of which were enforced.

"Two beds were used, a coarse and a fine bed, each having an area of one-eighth of an acre. Therefore, one quarter of an acre was required (by both beds) for the treatment of 100,000 gallons; and it follows that one acre of beds, half being coarse and half being fine beds, would deal with 400,000 gallons a day only. This was considerably less than had been anticipated. During some months much more than this was being treated. Thus, while the beds were being filled three times a day, with an average of 54,000 gallons per filling, 162,000 gallons a day were really treated. It was found, however, that after a few weeks the beds gave signs of being overworked.

"It is probable that in working with three fillings a day of crude or screened sewage it would be necessary to give the beds a rest of one week in four. This would equal 121,500 gallons a day, equal 486,000 gallons an acre," or, on the coarse bed only, 972,000 gallons per acre. As the fine bed retained its capacity, this would continue to work at the full rate of 60,000 gallons per filling, which, multiplied by three, equals 180,000 gallons, or 1,440,000 gallons per acre per day.

In dealing with sewage settled one hour, the working capacity was found to be 598,320 gallons an acre for the two beds, or for the coarse bed only 1,196,640 gallons per acre.

The report then concludes with the following:—"The Council will see that the subject is complex; but it is interesting to note that the whole drift of modern scientific thought in regard to sewage treatment is in the direction of biological treatment—is, in fact, a return to nature's methods in disposing of animal and vegetable decay by means of the countless organisms in the upper layers of the soil, the chemical action of which is being year by year increasingly investigated and understood."

The fact that the bacterial action in porous beds, as originally worked out at Barking and Sutton, is fully competent to effectually purify the sewage of Leeds is established. The only factors which further experience will elucidate is as to the best means of keeping the mineral and more resistant organic matters from clogging the beds, and the area, &c.

This would appear to be accomplished best by subsidence in either open or closed tanks, but after careful consideration

of the whole of the results of the work at this excellent experimental station, it would almost seem that the safest course to pursue would be to continue the precipitation of the iron salts, &c. by means of lime as hitherto, and to treat the effluent on contact beds as at Barking. Evidently economy may be overstrained.

In continuation of these experiments the committee tried various modifications of the simple bed system, amongst these being the septic tank, followed by the bacteria beds, Mr. Scott Moncrieff's multiple nitrification trays, and Messrs. Whittaker and Bryant's sprinklers, which distribute the sewage on an elevated open-sided filter on the lines of that proposed by Colonel Ducat.

In July, 1900, the second report was issued and signed by Colonel Harding, Mr. Hewson, and Mr. W. H. Harrison, M.Sc., the chemist to the committee, from which the following excellent summary of the results then arrived at is taken :—

General Observations on Experiments with Contact Beds.

If a sample of Leeds sewage is filtered through filter paper, the withdrawal of the solids in suspension gives a purification of about 50 per cent.

Chemical precipitation brings about a similar result, from 45 to 50 per cent. purification, though in some cases somewhat better results are obtained on account of the action of the precipitant in throwing down some of the matters in solution.

After the solids in suspension have been removed from sewage there remains a liquid, which is often clear and free from smell when it first leaves the tanks, but which still contains in solution about 50 per cent. of the impurities originally in the sewage. This liquid on standing or being turned into a stream becomes dark coloured, putrefies, and gives off offensive smells.

The treatment of sewage therefore resolves itself mainly into two parts :—

1. Dealing with matters in suspension.
2. Dealing with those in solution.

Chemical precipitation deals mainly with the first, and in actual practice accomplishes little in regard to the second; and its effect in regard to the first is at the cost of great production of sludge which has to be dried or pressed and removed, and has little or no agricultural value.

The object of the experiments was therefore:—

1. To bring about a higher degree of purification than can be attained by mere precipitation with or without chemicals.
2. To see how far it might be possible by bacterial action to do away with sludge production, or at least to reduce it.

The experiments were chiefly with double contact beds, a rough and a fine bed working in pairs, numbers 1 and 2, 3 and 4, and 5 and 6.

This system of artificial filtration was found to bring about a purification of from 75 to 95 per cent., but it is more effective in regard to matters in solution than to those in suspension which are more slowly reduced, and of which the undigested or indigestible portions tend to accumulate and choke the beds.

The filtrate from the rough beds, which is an intermediate and not a final result, was always dark coloured, with some smell, and was usually putrescent in character. The last flow showed signs of anaërobic fermentation, and sometimes deposited sulphur. This would lead to the conclusion that the process is not, at least in the lower portions of the rough bed, a strictly aërobic one.

The first flow from the fine beds is usually somewhat turbid and unsatisfactory, owing to insufficient aëration in the lower parts of the beds, and in the channels and pipes; and also to accumulation of solid matter in the neighbourhood of the outlet valves. On the other hand, the last part of the flow is exceptionally good, and therefore all the samples analysed are the average of the whole flow, spreading over an hour, and taken every ten minutes.

As a rule, the rough beds were found to keep back from 65 to 75 per cent. of the solids in suspension, and the filtrate showed a purification of about 65 per cent. The filtrates from the fine beds showed a purification on the crude sewage of from 75 per cent. to 95 per cent.

The solids in suspension in this final filtrate amounted to 3·51 grains per gallon when dealing with crude sewage; 2·19 grains per gallon when dealing with screened sewage; 1·3 grains per gallon when dealing with partially settled sewage; and these differences account for the turbidity noticed in connection with the first flow while dealing with crude or screened sewage, and for the improved appearance of the effluent in dealing with partially settled sewage; and there can be no doubt that with thoroughly settled sewage admirable results would be obtained by double filtration.

From experience gained during over two years in treating Leeds sewage on contact beds, it was found that whether dealing with crude sewage, screened sewage, or partially settled sewage, variable but very good effluents could be obtained, much superior to those from lime precipitation. Their chemical analyses gave results which were generally well within the limit of one grain per gallon oxygen absorbed and ·1 of albuminoid ammonia: limits which have in recent years been accepted by the Lancashire and Yorkshire Rivers Boards as a provisional standard of purity for effluents going into a stream not used for drinking purposes.

The following (Table XXIII.) are the average analytical results obtained over long periods, as detailed in the preceding pages:—

Table XXIII.

Table showing the Average Analyses of the Crude Sewage and the various Filtrates from Nos. 1, 2, 3, 4, 5, *and* 6 *Contact Beds.*

Grains per Gallon.	Date.	Total Solids.	Suspended Solids.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitrogen as Nitrates.
Crude Sewage.....	Oct. 27th, 1898, to Oct. 9th, 1899.	117·0	40·7	1·72	·809	8·04	—
Filtrate from Bed No. 1.		75·3	11·5	1·09	·318	2·48	—
,, ,, No. 2.		68·4	1·9	·318	·081	·50	·392
Percentage Purification effected by Bed No. 1.		—	71 %	36 %	60 %	69 %	—
Percentage Purification effected by Beds Nos. 1 and 2.....		—	95 %	81 %	90 %	93 %	—
Crude Sewage.....	Nov., 1898, to June, 1900.	118·4	42·9	2·03	·964	8·80	—
Filtrate from Bed No. 3.		82·3	12·6	·920	·289	2·07	—
,, ,, No. 4.		73·0	3·3	·581	·108	·655	·261
Percentage Purification, Bed No. 3		—	70 %	54 %	70 %	76 %	—
Percentage Purification, Beds Nos. 3 and 4		—	92 %	71 %	88 %	92 %	—

TABLE XXIII.—*continued.*

Grains per Gallon.	Date.	Total Solids.	Suspended Solids.	Free NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitrogen as Nitrates.
Crude Sewage.....	Mar., 1899, to Nov., 1899.	124·8	46·8	2·02	·997	9·12	—
Filtrate from Bed No. 5.		81·9	13·7	1 23	·397	2·91	—
„ „ No. 6.		71·5	3·3	·666	·141	·790	·127
Percentage Purification, Bed No. 5		—	70 %	39 %	60 %	68 %	—
Percentage Purification, Beds Nos. 5 and 6		—	92 %	67 %	85 %	91 %	—

These results were obtained notwithstanding the large volume and variety of trade effluents mixed with Leeds sewage. The chief difficulty occurred in connection with large quantities of iron liquor (ferrous sulphates and chlorides) coming down in this sewage, and representing as much as five tons of metallic iron per twenty-four hours. Generally a large part of this iron was retained by the beds; but at times, especially in summer, some of it came through in solution and afterwards settled out as a buff-coloured flocculent hydrated ferric oxide.

The final effluent evidently contained abundant dissolved oxygen, for it was found to support fish life; coarse fish, such as carp and gold fish living in it for long periods, some of them for over two and a half years; while there was much green growth in the basin and channels. Mention may be made of Vaucheria, an alga which grows in swift flowing and therefore well aërated streams. The usual pond life was also represented in great variety in the basin, including larvæ of Chironimus, Nais, Cyclops, small worms, &c. In the body of the filter were earth worms and great numbers of Podura aquatica. These evidences of aëration are a special and valuable feature of biological effluents, which, unlike the effluents from chemical precipitation, are rarely liable to subsequent putrefaction, but, on the contrary, contain elements of further purification and improve on passing to the streams.

It was found that new beds required about six weeks to get into condition, the early effluents being unsatisfactory and putrescent; but at the end of this period a rapid and permanent improvement in the filtrate took place.

The process of treatment of sewage on these contact beds was found free from nuisance, and even on digging deep into the beds which had received sewage for long periods, there was no smell but that peculiar to garden soil. It was found that stray seeds falling on the coke beds led to luxuriant growth of grass and other plants.

In these experiments analysis never showed any important percentage of nitrates, which, indeed, only began to appear after two months' work, and never exceeded ·6 per gallon, the average being considerably less. This was probably due to the composition of Leeds sewage which includes readily-oxidisable trade effluents.

As bacterial action is only possible within a limited range of temperature, careful records were kept to determine if in cold weather the temperature of the beds was liable to fall below that limit.

An examination of these records shows that the temperature of the beds is determined by the sewage, and only in a very minor degree by the atmosphere. This is illustrated in the following table:—

TABLE XXIV.—*Average Temperature of Sewage, Atmosphere, and Rough and Fine Dibdin Beds during a Period of Six Months.*

(Temperatures are in degrees F.)

Average Temperature from	Temp. of *Sewage* sent on to Rough Bed.	Rough Bed (No. 1).					Fine Bed (No. 2).				
		Temp. of *Atmosphere* at time of filling.	Temp. of *Bed* immediately before filling.	Temp. of *Bed* when full.	Temp. of *Filtrate*.	Temp. of *Bed* when empty.	Temp. of *Atmosphere* at time of filling.	Temp. of *Bed* immediately before filling.	Temp. of *Bed* when full.	Temp. of *Filtrate*.	Temp. of *Bed* when empty.
Dec. 17th to Dec. 30th, 1898	54·7	38·8	56·1	55·5	55·3	55·2	41·3	54·8	54·8	55·1	55·0
Dec. 31st to Jan. 13th, 1899	52·0	39·2	51·9	51·7	51·9	51·5	39·4	50·9	51·1	51·2	50·9
Jan. 14th to Jan. 27th, „	51·9	36·7	51·9	51·2	51·4	51·3	37·7	50·9	50·9	51·0	50·9
Jan. 28th to Feb. 10th, „	52·9	38·5	53·0	51·9	52·3	52·4	39·4	51·4	51·8	51·5	51·3
Feb. 10th to Feb. 24th, „	54·6	39·7	54·0	53·6	53·8	53·5	40·2	52·5	52·8	52·6	52·5
Feb. 25th to Mar. 14th, „	58·9	41·3	57·1	57·2	57·5	57·2	41·6	54·3	54·5	54·8	54·3
Mar. 15th to Mar. 25th, „	56·5	35·7	56·4	56·7	56·9	56·5	34·8	54·8	57·3	57·1	56·1
Mar. 26th to Apr. 8th, „	55·1	47·3	55·3	55·0	55·2	55·1	47·6	55·1	55·1	55·2	54·8
Apr. 10th to Apr. 21st, „	55·3	42·4	54·4	54·8	54·9	54·6	42·2	53·7	53·4	53·9	53·9
Apr. 22nd to May 6th, „	58·5	52·7	57·3	57·8	58·2	57·7	47·9	56·1	57·3	57·3	56·8
Average	55·0	41·2	54·7	54·5	54·7	54·5	41·2	53·4	53·8	53·9	53·6

It will be seen that in the eight hours occupied in passing through both beds the loss of temperature from the sewage to the final effluent was only 1½ degrees. During periods of rest the heat in the beds rose to 70 and 80 degrees.

During the past few years the winters have not been severe, and it was only during last winter that any valuable data bearing upon this subject could be collected. They show that during fairly cold winters the purification effected by this process of contact filtration is not appreciably checked.

Table XXV.

Table showing effect of Frost upon the Beds.

(Temp. = °F.)

Date. Fortnight ending	State of Weather.	Rough Bed (No. 3).						Fine Bed (No. 4).					Percentage Purification as calculated on Alb. NH_3 Test.	Percentage Purification as calculated on Oxygen absorbed Test.
		Temp. of Sewage.	Temp. of Atmosphere.	Temp. of Bed before filling.	Temp. of Bed when full.	Temp. of Filtrate.	Temp. of Bed when empty.	Temp. of Atmosphere.	Temp. of Bed before filling.	Temp. of Bed when full.	Temp. of Filtrate.	Temp. of Bed when empty.		
Dec. 8th, 1899	No Frost	58·9	45·5	56·3	57·2	56·7	55·9	45·5	54·8	54·8	54·6	54·5	90 %	93 %
Dec. 8th to Dec. 29th	Frost	53·1	31·2	49·8	49·8	49·4	49·2	31·9	47·4	46·1	46·1	46·0	91 %	92 %

The process then was reliable to give satisfactory effluents, and the real difficulty was found to be the impossibility of maintaining the capacity of the rough beds, except with such a slow rate of work that the area of rough beds required would be very costly.

The loss of capacity was due to the following causes, some of which are remediable and others not:—

1. *The passing of sand, coal dust, and road detritus into the bed.*—These matters must be kept out, for bacterial action cannot reduce them. The sewage must be passed first through a grit tank at such speed that only the heavier matters, with some of the grosser organic solids, are left behind.
2. *The degradation of the material of the filter.*—It is found that coke, though at first carefully sorted to larger size, soon becomes broken down. No doubt this arises to a less extent with clinker, which, however, is apt to take the form of slabs, and is not very suitable for a coarse bed. Burnt ballast is very liable to reduction.
3. *The consolidation of the material of the bed.*—As pointed out in connection with the single contact beds, Nos. 7 and 8, the loss of capacity in those cases was largely due to this cause. The material of a bed must be of very even size, or gradually the smaller pieces, by the slight movement due to filling and emptying, tend to fit themselves in between the larger, so as to approximate to a solid mass. As we have seen, even equal sized material in course of time becomes broken down into unequal, and so consolidation takes place.
4. *More organic solids coming on to the bed than the bed can digest.*—Fibre and certain vegetable matters are very slowly dissolved, and tend to accumulate in the beds, unless the rate of working is very slow. The screening-off of some of these matters can be accomplished within reasonable cost.
5. *The presence in the sewage of matters which cannot be reduced by bacterial action*, other than the sand and road detritus which it is suggested can be settled in the grit tank.

   Whether such matters exist in the sewage in an originally irreducible form, or whether such irreducible form is reached as a result of change in the bed, it is difficult to determine. But it is certain that a coarse bed which has been long at work is found to contain a large quantity of matter akin to humus or garden soil, and which cannot be further reduced. The same result was found in connection with the deposit in septic tanks and the suspended solids in their effluents.

6. *The retention in the bed of mineral solids originally in solution, but which, by the oxidizing action of the beds, come into suspension:* as, for instance, the iron liquors containing ferrous sulphates and chlorides, a large part of which are found to be retained in the beds, the pieces of coke being often heavily coated with red iron deposit.

It may be said that such matters should be kept out of the sewers. This is easier said than done, and it is of course to the interest of municipalities not to put difficulties into the way of trade; and the treatment of these liquors, so as to deposit the iron before they are allowed to pass into the sewers, would be a costly process for which many manufacturers have not land available.

When the experiments with No. 1 bed were stopped, the material was taken out, and that coke only replaced which could not pass through 1½-in. mesh. This was found to only half fill the bed, so that what passed through 1½-in. mesh and was rejected represented half the contents of the bed. A careful examination of this rejected matter gave a volume of 45·25 per cent. as made up of broken-up coke. Therefore, if a material could have been used not liable to degradation, probably one-third of the loss of capacity would have been avoided. 20·39 per cent. by volume of the remainder was true deposit, but contained 70 per cent. water. It had been to some extent dried or drained by the resting of the bed, and no doubt in working conditions the deposit would contain nearly 90 per cent. of water. Every grain of matter retained by the bed holds up 9 grains of water, so that the accumulation consists largely of water retained by the spongy matter. This matter itself was to the extent of 46·6 per cent. ferric oxide and sand and 36·5 was organic matter.

It is noteworthy that as the rough bed became choked, it became in effect a finer bed, and gave improved filtrates; but, on the other hand, it on that account more readily kept back solid matters, and towards the end the choking proceeded at a more rapid rate. If, when the capacity of the bed had fallen to 45,000 gallons, the rate of work had been reduced to one filling a day, as was done when the capacity had fallen to 25,000, no doubt the No. 1 bed might have gone on working very much longer.

It should be noted that the fine coke bed of the first series, No. 2, which has been working for 2½ years has not given much cause for anxiety as to the maintenance of capacity. The clinker fine beds, Nos. 4 and 6, on the other hand, have been appreciably reduced in capacity, which may be due to consolidation brought about by the greater specific gravity of the clinker as compared with coke.

The general conclusion, then, in reference to the Leeds experiments with contact beds, is, that in the conditions at Leeds, and with the material used, it was found impracticable to deal with crude or with partially settled sewage, not because good effluents could not be obtained, but because the capacity of the rough bed could not be maintained; and when accumulations arose, a large part of them having reached an irreducible stage, could not be consumed by resting the beds.

If, therefore, contact beds are to be used for Leeds sewage in future, the problem will be:—

1. To find material of perfectly even size not liable to degradation.
2. To reduce as far as possible the solid matters put on to the rough bed.
3. To exclude and treat separately the iron liquors.

Another point suggests itself, whether it would be possible to construct the beds in such a way that the undigested or indigestible solids shall be expelled from the beds with the effluents. This suggestion is dealt with later in this Report in reference to experiments in continuous filtration.

Table XXVI.

Table showing the Variations in Capacity of Contact Beds.

No. 1, ROUGH CONTACT BED.

	Galls.
Capacity before putting in Coke	= 174,800
Original Water Capacity after putting in the Coke ..	= 83,300

1897.	Galls.		
Oct. 1st	83,300	Crude Sewage (3 fillings).	
Nov. 1st	74,000	Do.	Do.
Dec. 1st	64,000	Do.	Do.
1898.			
Jan. 1st	57,100	Do.	Do.
Feb. 1st	45,400	Do.	Do.
	Bed rested 14 days.		
Feb. 18th ..	55,900	Lime Effluent.	

TABLE XXVI.—No. 1, ROUGH CONTACT BED—*continued.*

	Galls.
Capacity before putting in Coke	= 174,800
Original Water Capacity after putting in the Coke ..	= 83,300

1898.			
Mar. 1st	53,000	Screened Sewage (3 fillings).	
Apr. 1st	45,000	Do.	Do.
Apr. 27th ..	40,000	Do.	Do.
	Bed rested 7 days.		
May 5th	45,800	Do.	(2 fillings).
June 16th ..	43,200	Do.	Do.
	Bed rested 38 days.		
July 28th ..	56,500	Do.	Do.
Sept. 1st	42,000	Do.	Do.
	Bed dug over.		
Oct. 1st	46,500	Half-settled Sewage (2 fillings).	
Nov. 1st	44,000	Do.	Do.
	Bed rested 14 days.		
Dec. 1st	45,000	Do.	(3 fillings).
1899.			
Jan. 1st	36,000	Do.	Do.
Feb. 1st	31,800	Do.	Do.
		Resting on Sundays.	
Mar. 1st	29,000	Crude Sewage do. (3 fillings).	
Apr. 1st	25,000	Resting Wednesdays and Sundays.	
May 6th	22,700	Resting alternate days (*i.e.*, 1½ fillings per day).	
June 3rd....	23,400	Do.	Do.
July 1st	25,600	Do. (1 filling every day).	
Aug. 1st....	26,800	Do.	Do.
Sept. 9th....	27,300	Do.	Do.
Oct. 7th	26,900	Do.	Do.

N.B.—The increase of Capacity from July 1st, 1899, is more apparent than real, as with only one filling per day the Bed would have a longer time to drain.

TABLE XXVII.

No. 3, ROUGH CONTACT BED.

	Galls.
Capacity before putting in Coke	= 102,094
Original Water Capacity after putting in the Coke ..	= 51,800

	Galls.		
1898.			
Nov. 21st ..	51,800	Partially Settled Sewage (3 fillings). Rested on Sundays.	
Dec. 5th	46,600	Do.	Do.
1899.			
Jan. 2nd....	38,100	Do.	Do.
Feb. 1st	34,500	Do.	Do.
Feb. 13th ..	30,400	Grit Settled Sewage (3 fillings). Rest on Sundays.	
Mar. 1st	28,500	Do.	Do.
Mar. 27th ..	23,600 Rested 18 days.	Do.	Do.
Apr. 18th ..	28,600	Do.	Do.
May 2nd....	21,700 Surface removed.	Do.	Do. Beds rest alternate weeks.
May 31st ..	24,900	Do.	Do.
June 28th ..	22,500	Do.	Do. Resting alternate days. (3 fillings).
Aug. 1st....	25,000	Do.	Do.
Sept. 1st....	25,000	Do.	Do.
Oct. 1st	24,500	Do.	Do.
Nov. 1st	21,200	Do.	Do.
Dec. 1st	21,700	Do.	Do.
1900.			
Jan. 1st	18,000	Do.	Do.
Mar. 10th ..	14,700 Rested 16 days and Surface cleaned.	Do.	Do.
Mar. 26th ..	21,200	Do.	Do.
Apr. 1st	21,000	Do.	Do.
May 1st	18,500	Do.	Do.
June 1st	18,000	Do.	Do.
July 1st	18,200	Do.	Do.

N.B.—The increase of Capacity from July 1st, 1899, is more apparent than real, as with only one filling per day the Bed would have a longer time to drain.

TABLE XXVIII.

No. 5, ROUGH CONTACT BED.

Galls.

Capacity before putting in Coke .. .. .. = 102,094

Original Water Capacity after putting in the Coke .. = 53,100

	Galls.		
1899.			
Feb. 28th ..	53,100	Grit Settled Sewage. Rest on Sundays.	
Mar. 14th ..	46,600	Do.	
Apr. 1st	42,000	Do.	
May 9th	32,500	(2 fillings per day).	4 hours' contact.
June 1st	30,500	Do.	Do.
July 5th	29,400	Do.	2 hours' contact.
Aug. 2nd ..	29,400	Do.	Do.
Aug. 16th ..	29,900	Do.	4 hours' contact.
Sept. 13th ..	28,300 Rested 25 days.	Do.	Do.
Oct. 24th ..	30,800	Do.	Do.
Nov. 22nd ..	25,400	Do.	Do.
1900.			
Mar. 9th....	27,600	(3 fillings per day).	2 hours' contact.
Apr. 6th....	23,000	Do.	Do.
May 4th	18,100	Do.	Do.
June 1st	13,200 Rested 20 days and Surface cleaned.	Do.	Do.
June 22nd ..	20,500	Do.	Do.
July 20th ..	16,600	Do.	Do.

TABLE XXIX.

No. 7, SINGLE CONTACT BED.

Original Water Capacity after putting in the Coke .. = Galls. 55,700

	Galls.	
1899.		
Mar. 24th ..	55,700	Lime Effluent.
Apr. 21st ..	50,308	Do.
May 5th	48,600	Do.
June 2nd ..	43,600	Do.
July 1st	38,000	Do.
Aug. 1st	33,000	Do.
Sept. 1st	28,500	Do.
Oct. 20th ..	21,600 Bed rested and turned over.	Do.
1900.		
Jan. 3rd	53,500	Do.
Feb. 2nd....	50,300	Do.
Mar. 1st	46,000	Do.
Apr. 1st	41,000	Do.
May 1st	36,500	Do.
June 1st	31,000	Do.
July 5th	25,600	Do.

TABLE XXX.

No. 8, SINGLE CONTACT BED.

Original Water Capacity after putting in the Coke .. = Galls. 29,500

	Galls.	
1899.		
Mar. 23rd ..	29,500	Septic Tank Effluent.
Apr. 6th	29,800	Do.
May 4th	27,100	Do.
June 2nd ..	23,000	Do.
July 1st	18,500	Do.
Aug. 1st	16,000	Do.
Sept. 21st ..	10,700	Do.
	Bed rested and turned over.	
Nov. 10th ..	26,900	Do.
Dec. 1st	24,500	
1900.		
Jan. 1st	19,500	
Feb. 1st	17,000	
Mar. 1st	16,000	
Apr. 1st	13,500	
May 4th	12,200	
June 1st	9,800	
July 1st	11,000	

General Observations upon Septic Tanks.

When a septic tank is first started, a simple deposition of the suspended matters occurs, the effluent obtained being in reality only settled sewage. Soon, however, a fermentation of the deposited solids takes place, and a large volume of gaseous products is evolved. The period elapsing between the starting of the tanks and the occurrence of the phenomenon varies with the state of the weather, being shortest in summer. This evolution of gas gradually increases until sufficient has accumulated in the deposit to raise large portions of the latter to the surface of the liquid, where part of them remain supported by gas. These, exposed to the air and sun, become dried on the surface and hardened. They accumulate at first to the windward of the tank, and gradually spread over the whole surface; corks, matches, and the lighter matters forming part of the mass, which, during the hot summer months, often attains in parts to a thickness of over one foot. During the winter months, and especially immediately after periods of severe frost, this surface layer shows a decided tendency to become thinner.

Whilst these changes have been taking place in the contents of the tank, the character of the effluent obtained has also altered. At first the outflow has all the characteristics of settled sewage, and at Leeds is yellow in colour owing to the presence of iron. As the putrefaction of the sediment in the tank proceeds, the effluent becomes darker coloured and almost black, and somewhat offensive, owing to the solution of some of the products of bacterial action and the production of sulphides of iron.

The gases evolved are inflammable, and no doubt with a sufficient area of *covered* septic tanks they might be used for heating and lighting purposes.

The question whether septic tanks should be closed or not is of importance in view of the considerable extra cost of roofing them in. The advantages claimed for closed tanks are:—

1. That the roofing excludes the air from the surface, and promotes better anaërobic conditions.
2. That the resultant gases are under control, and can be utilised for lighting or heating.
3. That evil odours are prevented from escaping.
4. That the heat of the sewage is better maintained.

The experience of Leeds shows that whatever results were obtained from the closed septic tanks were equally well obtained by the open, and that the scum which forms on septic tanks itself soon gives a cheap automatic roof, which is chiefly of value in preserving the heat in the sewage, the floating surface being a bad conductor.

It was found that the average loss of heat of the sewage in passing through the open septic tanks was 1·6 degrees F., while through the closed it was ·8 degree F., and the difference is too small to warrant the expense of a roof on this account.

The heating value of the gases is not great, and the roofed-in septic tanks are really gas-holders, and, except under proper care, may become a serious source of danger.

In the open septic tanks the gases produced are at once dispersed. For the most part they are inodorous, no appreciable nuisance having arisen, though the effluent itself is more or less offensive. But Leeds sewage is diluted and mixed with trade effluents, and no doubt where strong domestic sewage is being treated greater nuisance may arise, and the roofing become necessary.

In appearance the effluents obtained from the open and closed septic tanks were identical, whilst from a chemical point of view no distinct difference can be detected.

Table XXXI.

Average of Analyses referring to Effluents from Open and Closed Septic Tanks.

Grains per Gallon.	Total Solids.	Suspended Solids.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed (4 hrs., 80° F.).
Effluent from OPEN Septic Tank (No. 1)	77·6	13·1	1·83	·455	4·18
Effluent from CLOSED Septic Tank (No. 1)	77·9	12·8	1·8	·437	4·82

By the putrefactive changes taking place in these tanks, a fair proportion of suspended matters present in Leeds sewage (it was 40 per cent. in No. 1 open septic tank) can be transformed into gases and soluble solids. Part is carried forward by the effluent, and is further treated upon the various filters, and part is left behind in the tanks and there accumulates.

An analysis of the dry sludge in No. 1 septic tank showed a loss on ignition of 55·4 per cent., leaving an ash of 44·5 per cent., of which 34·8 per cent. was ferric oxide, and 47·1 per cent. silica, so that nearly half of it is in a form not further reducible by bacterial action.

From time to time some of the sludge will have to be removed, but it is desirable to do so without the necessity of emptying the tank and having to start septic action *de novo*, a process which takes several

months to develop. Since there must be from time to time a removal of some of the matters in a septic tank, and since possibly some difficulty may arise from the offensive character of the septic sludge, it may be well to work septic tanks in series. In that case, as previous pages show, if the flow is at the twenty-four hours' rate through four equal tanks, it will be at four times that rate through each, and consequently there will be such rapid settlement of the heavier solids in the first tank, that it will be full before septic action arises there to any important extent. If this first tank therefore is in duplicate, it might be emptied altogether from time to time, and if it is also used as a grit tank the sludge will be dense, with a relatively small proportion of water, and in a condition less offensive than that of the thin black septic sludge.

A point of great importance to settle is the question as to which rate of flow through these tanks gives the best results. With the intention of obtaining some data bearing upon this subject, experiments previously detailed were instituted with three tanks, similar in every respect, through which sewage was passed at rates which would fill the tanks in twelve, twenty-four, and forty-eight hours. These experiments have not been in progress for a sufficient length of time to allow of any definite statement being made; but so far, it would seem as if any increase of flow above what is sufficient to fill the tank in twenty-four hours is attended with a corresponding decrease in the quality of the effluent, whilst a reduction of speed to the forty-eight hours' rate gives very little advantage. If the flow is increased too much the tank will become filled with sludge before septic action is produced.

Table XXXII.

Average of Analyses referring to the Effect of Different Rates of Flow through Open Septic Tanks.

Grains per Gallon.	12 hours' Flow.	24 hours' Flow.	48 hours' Flow.
Total Solids in effluent	88·0	78·2	78·6
Solids in Suspension in effluent	19·6	11·5	10·9
Free Ammonia	1·41	1·50	1·55
Alb. ,, ...	·502	·348	·377
Oxygen absorbed (4 hrs., 80° F.)	5·71	4·37	4·27

It has previously been stated that sulphide of iron is present in the effluent from the Leeds septic tanks, and this would lead to the supposition that a large amount of iron is precipitated in the tanks and remains there. Analysis shows, however, that only 30 per cent. of the iron in the sewage remains behind, whilst effluents have been obtained in which as much as 40 per cent. of the total iron is in solution.

Briefly, the advantages found in the use of septic tanks were:—

1. The production of a practically uniform effluent from sewage of such varying composition as that of Leeds.
2. The digestion of part of the solids in suspension, which at Leeds amounted to about 40 per cent. of those originally in the sewage.
3. The anaërobic putrefaction which takes place in the septic tank facilitates subsequent filtration, rendering the filtrate less liable to secondary putrefaction.

Whittaker Beds.

Councillor Whittaker, the chairman of the Accrington Sewage Committee, having brought under the notice of the Leeds Committee the advantages of continuous filtration following on septic treatment, a bed on his system was constructed for experimental purposes at Knostrop.

The bed is circular, and not having to stand any pressure of water is merely surrounded with wood laths kept together by iron bands. Within this light screen the clinker is piled up. The bottom consists of a circular layer of concrete, having an 18-inch collecting drain running along one diameter, and which has a fall of 1 in 45. This drain forms the main carrier for the filtrate, and is perforated on the half with small holes, and with larger holes in the sides into which 9-inch pipes run, having a fall of 1 in 22 to the larger pipe. These smaller pipes are also perforated half round with small holes. Between these pipes cement is placed to the level of the lowest perforations, so as to prevent the stagnation of the filtrate.

A manhole rises vertically from the centre of the bed, having a diameter of 6 ft. and a height of 10 ft. 6 in., formed of open brickwork.

The clinker was between 3 in. and 1 in., except around the manhole and the extreme circumference, where a layer of very coarse clinker is placed.

Effluent obtained from the No. 1 open septic tank was pumped by means of a pulsometer to the Whittaker rotating sprinkler, and by it distributed in a shower over the whole surface.

The bed was started on 9th March, 1899, at the rate suggested by Mr. Whittaker, of 100,000 gallons per twenty-four hours, *i.e.*, at the rate of 3,000,000 gallons per acre per twenty-four hours. The first filtrates were exceedingly bright and clear, due no doubt to the suspended solids being at first retained by the bed, but the filtrate gradually became turbid. As the turbidity increased the analyses also gave worse results, *e.g.:* the average of the analyses on 9th and 12th March, 1899, was ·15 Alb. NH_3 and ·97 oxygen absorbed. As solids began to work out of the filter the results became worse, until on 28th March the analyses, including the solids in suspension, gave ·246 Alb. NH_3 and 1·66 oxygen absorbed.

On 24th March the top layer of the filter was covered with a deposit of iron, and the bed began to show signs of surface clogging, pools of water being formed upon it. On 4th April, 1899, the number of pools had increased so that the sewage began to run down the centre manhole and the sides. The flow was therefore reduced to 33,000 gallons per day, in order to see if this reduced quantity could be taken in. No improvement arising, two of the four arms of the sprinkler were stopped in order to make the sprinkling more intermittent. But still the effluent gathered in pools on the surface, though the reduced work given to the filter gave improved results: on 9th April, ·102 Alb. NH_3 and ·337 oxygen absorbed.

The bed was now allowed to rest from 13th April to 17th April, 1899. This rest allowed the surface to drain dry, but did not prevent the liquid pooling upon the surface on re-starting the bed. The filtrate obtained on the 17th was very good, containing ·77 nitrogen as nitrates; but from that date decreased in quality until 8th May, 1899, when it contained ·26 Alb. NH_3 and ·775 oxygen absorbed, whilst only a trace of nitrates was present.

The falling-off in the results was due to the surface being covered with an abundant gelatinous mycelium-like growth (Pylobolus), which prevented the effective aëration of the filter.

On 8th May the surface was removed to a depth of one foot in order to expose a new surface, it having been noticed that the growth did not extend to more than a few inches. On re-starting on 9th May, 1899, the filtrates were very clear and good, and continued so until 18th May, when, owing to the surface again clogging, the results again became unsatisfactory: *e.g.*, Alb. NH_3 = ·19; oxygen absorbed = ·842.

On 20th May, 1899, the bed was stopped and allowed to rest until 24th May. This rest only produced a slight improvement in the filtrate, and very little alteration to the surface clogging.

Mr. Whittaker's idea was that heating of the sewage as it goes upon the bed was not only valuable at all times, but absolutely essential in

cold weather, and that it was within practicable limits of cost, because he claimed to require a greatly reduced area of filter with heated sewage. The condensed steam of the pulsometer, mixing with the sewage, increased its temperature, and at Mr. Whittaker's desire steam was, in addition, directly injected. It was found that this increased the temperature of the septic effluent from 59 degrees, at which it left the tank, to 72·5. It was considered quite too costly to do this on a large scale, and as the growth on the surface of the bed appeared to be promoted by the heated effluent, the use of injected steam was discontinued, and it was found that by the pulsometer alone the heat of the septic effluent put on the bed was raised from 59 degrees to 67 degrees—about 8 degrees. This is not necessary during the warmer months; but with an unroofed open bed, worked on the continuous principle, there may be difficulty in winter weather.

On 30th May the process was stopped, and the bed allowed to rest until 13th June, 1899, when it was re-started at a rate of 50,000 gallons (*i.e.*, 1,500,000 gallons per acre) per twenty-four hours. The filtrates first obtained were very clear and good (Alb. NH_3 = ·08; oxygen absorbed = ·344), whilst a large amount of nitrates had been produced during this rest, as was evinced by the fact that the average sample for 14th June contained 3·5 grains per gallon of nitrogen as nitrates. The surface of the bed remained perfectly free from clogging until June 18th, and on June 26th, 1899, it became necessary to fork the surface. It was noticeable that this forking, by opening out the surface and the better aëration of the bed, caused better filtrates to be produced. The improvement continued until the surface of the bed again became clogged. It was therefore evident that for the production of good effluents it was necessary to keep the surface open.

As the clogging was due to a vegetable growth, which did not penetrate into the bed more than a few inches, it was decided to cover the surface of the bed, after thoroughly forking, with a layer of one foot in thickness of exceedingly coarse coke, which it was thought the growth would not choke. This was done on July 10th, 1899. A great improvement in the quality of the filtrates was produced, as shown by the great increase of nitrates, *e.g.*, on July 8th the nitrogen present as nitrates was ·49, and on July 13th ·756. The filtrate continued to be clear from July 10th to July 30th; but from the latter date, large quantities of brown suspended matters came out from the bed causing the values obtained from the Alb. NH_3 and oxygen absorbed tests to rise considerably. The free NH_3, however, remained very low (about ·2), whilst the N as nitrates remained over ·7 grain per gallon, showing that the aëration of the bed was not being interfered with. The coming through of these solids in suspension in the filtrate was at first very disappointing, and was looked upon as condemning the system.

Further experience, however, has shown that a large part of these solids are irreducible, and therefore, if they do not come out, but stay behind in the filter, they must necessarily choke it up. They were soon found to be non-putrescible and to be readily settled.

On October 3rd, 1899, the surface being again clogged, notwithstanding the fact that it consisted of coarse coke, the bed was allowed to rest for twenty-four hours. This produced no change, and therefore, from October 4th to October 11th, 1899, the bed was allowed a further rest. This rest not producing any appreciable result, the whole surface was thoroughly forked over.

On December 20th, 1899, the flow was further reduced to 250 gallons per square yard, *i.e.*, to 1,250,000 gallons per acre, this being the slowest rate at which the sprinkler could be kept rotating.

During the winter of 1899—1900 there were two severe periods of sharp frost, from December 9th to December 29th, 1899, and from February 2nd to February 15th, 1900. During both of these periods, although the outside of the bed was covered with icicles, it was found that the purification was not materially affected, because by the action of the pulsometer pump the temperature of the effluent going on to the bed was kept a few degrees above that of the sewage.

Table XXXIII.

Grains per Gallon.	State of Weather.	Septic Tank Effluent.			Filtrate from No. 1 "W." Bed.				Percentage Purification.	
		Free NH_3.	Alb. NH_3.	Oxygen Absorbed.	Free NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitrogen as Nitrates.	In Alb. NH_3.	In Oxygen Absorbed.
Nov. 24th to Dec. 8th, 1899	No Frost	1·47	·383	4·45	·809	·116	·730	·476	69 p.c.	83 p.c.
Dec. 9th to Dec. 29th, „	Frost	2·13	·481	4·36	·967	·129	·731	·283	73 p.c.	83 p.c.
Jan. 18th to Feb. 1st, 1900	No Frost	1·60	·463	4·10	·507	·075	·523	·597	83 p.c.	87 p.c.
Feb. 2nd to Feb. 15th, „	Frost	1·77	·442	4·46	·718	·111	·688	·731	74 p.c.	84 p.c.

Towards the beginning of April, 1900, the appearance of the filtrate greatly deteriorated. The suspended solids were dark coloured, and the supernatant liquid obtained after settling them out was opalescent, and sometimes threw down a buff-coloured precipitate similar to that from the contact-bed filtrates. This was caused by the accumulations of solids in the filter preventing the efficient aëration of the bed, and

also causing unequal distribution of the liquid throughout the filtering material. This choking up of the interior of the filter caused some of the liquid to run down the outside of the filter, and also down the manhole. The filter was therefore allowed to rest for ten days. On restarting the filtrate was again good, and remained so until May 1st, when signs of deterioration became apparent at the same time as leakage on the sides. On May 12th the bed was stopped, pending experiments in washing out the bed, which have not yet been carried out, and it is feared that the material which was used for this bed was too fine.

Table XXXIV.

Average of Analyses referring to Period from March 9th, 1899, to May 8th, 1900.

Grains per Gallon.	Total Solids.	Suspended Solids.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed (4 hrs., 80° F.).	Nitrogen as Nitrates.
Septic Tank Effluents.....	78·4	13·1	1·80	·434	4·02	—
Filtrate — Whittaker Bed, No. 1	69·8	5·6	·688*	·113*	·684*	·548*
Purification effected on Septic Effluent	—	57 %	61 %	73 %	83 %	—

* Analysis made after rough settlement of suspended solids.

Table XXXV.

The following Table is the Average of a Number of Comparative Analyses made upon the Filtrate from the Whittaker Bed, No. 1, with and without Suspended Solids.

Grains per Gallon.	Albuminoid Ammonia.	Oxygen Absorbed.
Filtrate containing Solids	·233	1·40
,, after Settlement of Solids	·105	·610

In view of the fact of the suspended solids being non-putrescent in character, the following analysis may be of interest. The sludge produced by the settlement of the filtrate was washed, and as far as possible freed from the larger living organisms, such as worms, larvæ:—

Loss on ignition	= 31·3	per cent.
Ferric oxide	= 31·3	,,
Silica and matter insoluble in acid .	= 18·9	,,
Other mineral matters . . .	= 18·5	,,
	100·0	

The filtering material of No. 1 Whittaker bed having been found to be too fine in character, it was decided to build a smaller bed and to fill it with very coarse coke.

The construction of this No. 2 bed was as follows: Rows of semicircular perforated tiles, having a diameter of 18 in., are placed edge to edge, and raised above a slight inclined plane of concrete by means of small brick columns, so that there is a clear air-space between the tiles and the concrete floor. Upon the floor thus constructed is built an octagonal pigeon-holed wall, and the space within this wall is filled in with coarse coke; first, to a depth of one foot above the pipes by coke not less than 2 inches in diameter, and the rest of the bed is then filled with coke of not less than 1½ inches diameter. Altogether, there are 9 feet in depth of coke.

The septic tank effluent is distributed over the surface by a Whittaker sprinkler, and the filtrate is collected by a channel running round the concrete floor.

The rate of filtration was 1,000,000 gallons per acre (*i.e.*, 200 gallons per square yard) per twenty-four hours, working night and day.

The bed was started on 2nd September, 1899. The first filtrates obtained were exceedingly clear but putrescent, showing that though solids in suspension were being kept back, bacterial action was not yet developed. This continued until 19th September, when the filtrate became turbid from the large quantity of suspended solids coming out from the coarse coke; but, nevertheless, nitrates were present, and the filtrates were non-putrescent in character.

Since then the filtrates have remained turbid, but non-putrescent, and no change has been made to the bed itself until 7th April, 1900, when the coke upon the surface, which had disintegrated somewhat, was renewed.

Work was continued night and day, till towards the middle of May, 1900, the quality of the filtrate obtained deteriorated. This was considered to be due to the accumulation of solid matter in the filter interfering with effective aëration, and also to some extent causing the liquid to be unequally distributed throughout the bed. The surface of the bed was also clogged to a small extent by the usual growth.

On 23rd May, 1900, an interesting experiment was made to see if the matter on the surface and the accumulations within the bed could be washed out. It had often been noticed that if for any purpose the arms of the sprinkler were held from rotating, then within a few minutes the filtrate became very turbid, with an excess of solid matter coming out. This was due to sending the whole volume, which, during the rotation of the arms, is distributed over the whole surface, through only a small part of it, and so increasing tenfold the flow through that part.

This suggested that, with a coarse bed like this No. 2, the bed could be washed out. Accordingly, a three-inch hose, with town's water, was turned on one square yard of the bed, and successively over the whole surface. The bulk of the accumulated solids came out in the first three minutes, during which the filtrate was exceedingly turbid, a test-tube with ten inches in it settling down three inches of sludge. After the first few minutes the number of solids coming through rapidly diminished. With these washed-out solids came out an immense number of cyclops, larvæ, &c. The sludge was found only slightly putrescent, although it would necessarily contain organic matter in process of transition. No doubt, if the experiment had been made after a rest of one or two days, the sludge would have been as little putrescent as that which comes out in the normal flow. The filtrates obtained immediately after this washing-out experiment were good, but soon afterwards became worse, although they remained non-putrescent. These bad filtrates continued to the middle of June, when they again improved, the nitrification being exceedingly good, viz., 1·31 grains per gallon of nitrogen as nitrates.

During the winter of 1899—1900 two periods of keen frost were experienced. Although on both of these occasions the bed was covered with ice, and the semi-circular pipes at the bottom of the bed were filled with large icicles, the purification was not materially interfered with.

Table XXXVI.

Grains per Gallon.	State of Weather.	Septic Tank Effluent.			Filtrate from No. 2 "W." Bed.				Percentage Purification.	
		Free NH_3.	Alb. NH_3.	Oxygen Absorbed.	Free NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitrogen as Nitrates.	In Alb. NH_3.	In Oxygen Absorbed.
Nov. 21th to Dec. 8th, 1899	No Frost	1·47	·383	4·45	·659	·077	·623	·658	79·8 p.c	81·5 p.c
Dec. 9th to Dec. 29th, „	Frost	2·13	·481	4·36	·670	·092	·586	·528	80·8 p.c	86·5 p.c
Feb. 2nd to Feb. 14th, 1900	No Frost	1·60	·463	4·10	·228	·056	·442	·823	87·9 p.c	89·2 p.c
Feb. 15th to Feb. 25th, „	Frost	1·77	·442	4·46	·498	·070	·519	·752	84·1 p.c	88·3 p.c

Table XXXVII.

Average of Analyses referring to Period from September 2nd, 1899, to June 30th, 1900.

Grains per Gallon.	Total Solids.	Suspended Solids.	Free NH_3.	Alb. NH_3.	Oxygen Absorbed (4 hrs., 80° F.).	Nitrogen as Nitrates.
Septic Tank Effluent	78·1	14·4	1·85	·455	4·18	—
Filtrate—Whittaker's Bed, No. 2	70·7	7·7	·532*	·079	·590*	·669
Percentage Purification on the Septic Effluent	—	46%	71%	82%	85%	—

* Analysed after the rough settlement of suspended solids taken from October 23rd, 1899, to June 30th, 1900.

Table XXXVIII.

The following Table is the Average of a Number of Comparative Analyses made upon the Filtrate from Whittaker Bed, No. 2, with and without Suspended Solids.

Grains per Gallon.	Albuminoid NH_3.	Oxygen Absorbed.
Filtrate, containing Solids.....	·183	1·27
,, after Settlement of Solids	·069	·523

General Observations on Continuous Filtration.

These experiments in continuous filtration by spreading sewage like rain upon a surface of coarse coke, well aërated at the bottom and sides, were interesting and important, and showed that in so short a time as the fifteen minutes required to pass through the bed, remarkable changes took place. It is true that to the eye the filtrate looks anything but satisfactory, but on holding it up to the light in a glass tube the turbidity is seen to be due, not to discolouration of the liquid, but to the presence of suspended solids, which soon settle down, leaving the liquid clear above. These solids are found to be absolutely non-putrescent, and, about half of them being ferric oxide and silica, are not further reducible by bacterial action, and if they do not come out must choke the bed. They involve, after filtration, a settling tank, the sludge from which would, for Leeds septic effluent, with an average of 13 grains suspended solids, be equivalent to six tons of sludge per million gallons. It dries readily, without giving rise to any nuisance. The final filtrate, taking results over the whole period of working No. 2 bed, gives on analysis ·079 per gallon of albuminoid ammonia and ·59 per gallon of oxygen absorbed. This means a purification by the filtration of about 83 per cent. on the septic effluent put on to the bed, and a total purification by the septic tank and the filter of 92 per cent. on the crude sewage.

It is not suggested as practicable that continuous filters can be washed out by turning on a hose or town's water, nor is it desirable to so far wash out the bed as to wash out the bacterial life. The washing-out would be conveniently and automatically accomplished by increased flow during rain. Thus, if the normal flow of one million gallons per acre gave good results, and while bringing out solids in

suspension which must be afterwards settled, yet left behind some accumulation, this would be washed out as soon as the flow increased. Increasing the flow to three volumes will not damage the filter, though no doubt during such increased flow the degree of purification would not be so good.

The Whittaker sprinkler was not found very efficient, and required frequent attention and cleaning of the holes. There is room for much improvement in distributors.

It is proposed to try an experiment with continuous filtration on a coarse bed, well roofed in to conserve the heat in the sewage. The artificial heating proposed by Mr. Whittaker, it is feared, will prove too costly on a large scale.

Continuous Filtration of Crude Sewage.

In previous pages we have dealt with the double contact filtration of crude, screened, and settled sewage, and also with the continuous and contact filtration of septic effluent.

It was desired to investigate the possibilities of dealing by continuous filtration with more or less crude sewage. For this purpose three small experimental beds were used, which had been constructed for use as triple contact beds, but had not been put to work for that purpose. These beds were a little over 12 ft. square, and had an area of 17 square yards and a depth of 4 ft. The first of these was filled with the coarsest coke available, the second with coke to about 1 in. and 1½ in. in size, and the third with small coke about ⅝ in. The distribution was by tipping troughs, and the sewage used was the crude sewage after passage through three screens, the smallest of which was 37 per inch. The first of these screens, which had ⅛ in. mesh, kept back small pieces of paper, matches, &c., and the second and third screens kept back most of the fibre, but all the finely divided solids in suspension passed on to the beds. The keeping back of matter by the screens, although it greatly facilitated the work, did not remove any important proportion of the solids in suspension, the matters removed being those which usually do not come into the analysis, as paper, matches, fibre, &c.

The first filtrates from the fine bed were very clear, the suspended matter being at first entirely kept back by the coke; but after a few weeks the solids began to work through, and the filtrate became somewhat turbid, though giving fair analytical results when the solids had been settled. Trouble, however, arose in two directions, first by the development of a growth in the upper part of the coarse bed, and secondly by the pooling of the sewage on the surface of the finest bed.

It was soon found impracticable to go on dealing with crude sewage

over fine coke, even after passing over beds Nos. 1 and 2 filled with coarse coke.

These experiments were therefore stopped, the material taken out of No. 2 and 3 beds, which were then refilled with very coarse coke, 1½ in. and upwards. When this was done semi-circular perforated drain pipes, 9 in. in diameter, were placed in the bottom of each bed, thus reducing the coke depth in each case, but securing more effective aëration.

For the tipping troughs on No. 1 bed a Candy sprinkler was substituted. This sprinkler has two arms and works intermittently, sewage passing for one minute, followed by three minutes' rest. This intermittence, in sprinkling, was in some respects a disadvantage in connection with such coarse material, for the sewage passed through the beds in rushes. On the other hand the intermittence probably proved useful in improving the aëration of the first bed.

This second experiment was started on 26th March, 1900, at a rate of flow of 750,000 gallons per acre, that is 150 gallons per square yard per day.

It will be understood, therefore, that this continuous filtration was over three beds of the coarsest coke: the first 3 ft. 6 in., and the second and third about 2 ft. 6 in. each in depth; and no doubt it would have been much better to have had this 8 ft. 6 in. of coke all in one column, with a single distributor.

The sewage took only a quarter of an hour to pass through the three beds, and the first results were very unsatisfactory with a total purification of about 50 per cent. only. The filtrates gradually improved until in about three weeks the bed had got into condition, but shortly after this solids began to work through and made the filtrates turbid. This was the same result which had been noticed on the Whittaker beds; that the solids in suspension were at first kept back, but gradually worked their way down through the filter until they began to come out with the effluent. These solids were found, however, on coming out, to be different in character to what they were on going in. They settled more readily, and were very slightly putrescible.

When these solids had been settled from the final filtrate, good analytical results were obtained, namely: ·099 Alb. NH_3 and ·667 oxygen absorbed per gallon.

This result, in view of the short time taken by the sewage in passing over this very coarse coke, was certainly remarkable, but it will be seen that the process would require to be followed by a settling tank. The solids so settled would probably be found similar in character to those experimented with in the case of the Whittaker bed, and give rise to no nuisance in the drying of the sludge.

The growth on the top of No. 1 bed has not up to the present caused any inconvenience.

The following table gives the average of the analyses since the starting of the experiment, and including the early bad filtrates. It will be seen that these analyses, although including the solids in suspension, show a purification of 71 per cent. on the crude sewage measured by the Alb. NH_3, and 78 per cent. measured by the oxygen absorbed; but recent analyses made from the settled filtrate show a purification of 90 per cent. as measured by the Alb. NH_3, and 92 per cent. as measured by oxygen absorbed, and nitrates ·3.

Table XXXIX.

Average of Analyses referring to Period from March 26th to June 30th, 1900. Analyses are inclusive of all Suspended Solids.

Grains per Gallon.	Total Solids.	Suspended Solids.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitrogen as Nitrates.
Sewage	123·2	44·2	2·36	1·04	8·90	—
Filtrate from 1st Bed.....	87·6	19·2	1·58	·599	4·37	—
,, 2nd ,, ...	74·0	7·9	1·15	·430	2·78	—
,, 3rd ,, ...	71·7	7·7	·828	·297	1·93	·141
Percentage Purification	—	82 %	64 %	71 %	78 %	—

It was noticed that the solids in suspension coming out with the filtrate were very irregular in quantity, as if they were washed out in occasional rushes.

This interesting experiment has not been carried on long enough to enable any definite conclusions to be come to; but, so far as it goes, it shows that it would be possible, after screening off the coarser solids and the fibre, to deal with crude sewage by continuous filtration over very coarse material in such a way as to bring out the undigested solids, and to guarantee that the beds would not choke up. From the irregularity in the amount of solids coming out, it is evident that by increasing the flow the beds can be readily washed out.

No doubt with a somewhat increased depth of coke, and improved construction, the solids coming out could be obtained in an entirely non-putrescent condition.

As evidences of the aëration obtained in this process, it may be mentioned that on the wet surface of the third bed green confervoid growths have recently appeared.

One curious thing was noticed, that when the sewage put upon the beds was very considerably darkened by dye, the colour was completely taken out in the final filtrate, and indeed the greater part of the colour had disappeared from the filtrate in the first bed.

The experiment is being continued, and is thought to be sufficiently promising to make it worth while to make a new "Leeds" bed on these lines in one column with 12 feet of coke, with other modifications.

Ducat Filter.

An experiment has recently been started in the continuous filtration of crude sewage on a filter constructed on lines suggested by Colonel Ducat, of London. This filter has an area of $\frac{1}{100}$th of an acre (48·4 square yards) and a depth of 10 feet. The material used being clinker three-eighths inch to five-eighths inch. The sides of the bed are built, not of brick, but of drain pipes, 12 inches long and 5¼ inches external diameter. This construction secures the complete exposure of the sides of the filter to the air. Outside this perforated wall is a second wall, distant from it about three feet, and built of solid brickwork for the purpose of keeping in the heat, and it carries a roof covered with thatch. The bottom of the bed has six perforated brick channels connected with the outer air, through which pass cast-iron hot-water pipes connected with an external boiler, intended to supply artificial heat during cold weather. The crude sewage was raised to the level of the bed by means of a Tangye pump, and passed through a three-sixteenths inch screen and a small grit chamber. The distribution of the sewage was by means of tipping troughs. This construction is prohibitively costly.

The bed was started on 29th March, 1900, working alternate hours for ten hours, and resting for fourteen, the rate of flow while working being 200 gallons per square yard. The filtrate on 6th April was exceedingly clear and bright, suspended solids being retained in the bed. On 14th April the bed was worked for ten hours continuously, with fourteen hours' rest. This change immediately caused the filtrate to become opalescent, but after a day's working it again cleared. On 16th April the surface showed signs of choking, and small pools began to form. On 26th April the whole surface was practically covered with stagnant sewage; the filtrate steadily deteriorated, and at the same time a grey filamentous growth began to appear in one outlet basin, very similar in character to that found on the surface of the Whittaker beds.

The unsatisfactory character of the effluent led, on 27th April, to reducing the work to alternate hours' work for ten hours, with fourteen hours' complete rest. The change produced no alteration for the better, and on 30th April, 1900, the process was temporarily stopped.

It was found that practically all of the suspended matters had been arrested upon the surface, and, by preventing the efficient aëration of the filter, had produced the bad filtrates.

During the whole of this period the bed was warmed by means of the hot-water apparatus, the temperature of the filtrate being about 10 deg. Fahr. higher than that of the sewage.

The filter, when giving the best results, produced a purification of 90 per cent. in albuminoid ammonia, and 93 per cent. in oxygen absorbed upon the sewage sent on to the bed. The nitrogen present as nitrates in the filtrates also reached ·56 grain per gallon.

Table XL.

Average of Analyses referring to Period from March 29th to April 30th, 1900.

Grains per Gallon.	Total Solids.	Suspended Solids.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed (4 hrs., 80° F.).	Nitrogen as Nitrates.
Sewage	129·7	53·7	2·88	1·09	7·98	—
Filtrate	71·6	Nil.	1·00	·122	·711	·313
Percentage Purification	—	—	65 %	88 %	91 %	—

It was thought that the chief cause of the clogging was due to wool fibre passing the screen and so getting on to the bed. To obviate this the sewage, before going on to the bed, was now sent through a three-sixteenth inch screen, and then through a layer of the bed material 1 in. in thickness. Before restarting, the choked surface was removed to a depth of 2 in. and replaced by new material.

The bed was restarted on 13th June, 1900, filtering at the rate of 200 gallons per square yard for alternate hours for ten hours, followed by fourteen hours' rest. The filtrate at first was opalescent, but this totally disappeared by 15th June, leaving the filtrate exceedingly clear and bright.

On 20th June the bed began to work continuously for ten, and rest fourteen hours. This increased amount of work caused the filtrate to

become opalescent, but this had cleared off again by 22nd June. The filtrate remained clear until 24th June, when the filter was put to work continuously throughout the twenty-four hours. The opalescence again cleared off, leaving the filtrate very bright and clear. Green growth also began to appear in the basin.

During this period the hot-water pipes were not used. The temperature of the filtrate was on the average about 4 deg. Fahr. lower than that of the sewage. The *best* results obtained were as follows:—

Table XLI.

Average of Analyses referring to Period from June 13th to July 7th, 1900.

Grains per Gallon.	Total Solids.	Suspended Solids.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed (4 hrs., 80° F.).	Nitrogen as Nitrates.
Sewage	127·9	59·4	2·79	1·07	9·90	—
Filtrate	69·0	Tr.	·165	·043	·241	·848
Percentage Purification	—	100 %	94 %	96 %	97 %	—

But at the date of this report, after less than a month's work, signs are again appearing that the surface is becoming choked, and the filtrates are rapidly falling off in quality.

It seems quite unlikely that the crude sewage of Leeds can be dealt with on such fine material; but the experiment is being continued, and further light will no doubt be thrown upon it.

Concluding Notes.

Readers are referred—

For General Observations on Intermittent Filtration (contact beds), to p. 156 *et seq.*
For General Observations on Septic Tanks, to p. 170 *et seq.*
For General Observations on Continuous Filtration, to p. 181 *et seq.*
For Recent Experiments in Continuous Filtration of Crude Sewage, to p. 182 *et seq.*

This is necessarily an interim report, and no doubt, as the experiments are continued, fresh light will be thrown on this interesting and important subject.

The Corporation of Leeds has just purchased a large estate of 1,890 acres for purposes of sewage disposal, and several years will be required before the great volume of the sewage of the city and its dilutions can be conveyed to it.

There will therefore be time to continue the experiments, and to settle with certainty the best method of treatment for the local conditions.

CHAPTER X.

THE BACTERIAL TREATMENT OF FACTORY REFUSE.

It having been shown that bacteriological action is fully equal to the task of purifying domestic sewage under ordinary conditions, it remained to be ascertained whether sewage containing relatively large quantities of refuse from various manufactories could be treated on the same lines with equal success. As there has now been ample opportunity of testing this important point, I am able to give for the information of the reader the outcome of the work done in this direction.

It should first be pointed out that London sewage, upon which the whole of the earlier experiments were carried out, contains very large quantities of manufacturing refuse of all kinds. It has been frequently stated that up to quite recently domestic sewage only had been dealt with, and that when the method was tried in manufacturing towns it would probably fail. There is, of course, in the sewage of London no such preponderance of any particular kind of trade refuse as is found in some other towns, as, for instance, the iron pickle liquor in Leeds and West Bromwich, the refuse from the leather dressers at Yeovil, or the dye liquors in some of the northern towns; but it may fairly be said that, whilst the Sutton experiments were made with a purely domestic, although very strong sewage, the London, Manchester, and Leeds results were obtained from sewages containing all manner of trade refuse.

It will therefore be of interest to instance some experiments made with bacteria beds upon samples of actual trade refuse in the condition in which they were discharged into the sewer. In each case the liquid was allowed to remain in a coarse bed for two hours, and following this in a fine bed for a similar period of time.

Special trials made on refuse liquor from tanneries, margarine works, galvanising works, gas liquor, milk washings, and yeast washings showed that in all cases a very considerable improvement was effected, excepting in the case of the gas liquor, which had to be somewhat diluted before being placed in the beds. The resultant effluents contained no suspended solids, and did not become putrid on keeping.

After the beds had treated the iron liquors they became charged with ferrous salt, and on subsequently passing sewage through them, this was washed out and appeared in the effluent, thus showing that the action of the bed was first to store up the iron, especially in the fine bed, and then to yield it up again, a phenomenon which has been frequently illustrated by various observers in the case of ordinary filtration. It was noticed, however, that all the subsequent filtrates from this particular bed were water-white.

It will, of course, be understood that these samples are only given to show that the refuse liquors named are amenable to treatment on bacteria beds; the effluent so produced must not in any way be taken as representative of what is required in the way of purification. It is, however, clear that if so much work can be done by passage through two beds, the purification can be extended by increasing the number of times of submission to microbial influences. In practice, concentrated chemical refuse liquors would have necessarily to receive special treatment in order to fit them for bacterial purification; excess of acid or alkali must be corrected; iron, if present in large quantities, removed; and so forth. The

point which has been so far considered is as to the treatment of sewage containing manufacturing refuse; and, so far as experience has gone, such sewages can be efficiently purified by the bacterial method equally with the domestic sewage from a purely residential neighbourhood.

TABLE XLII.

DESCRIPTION OF SAMPLE.	Oxygen absorbed from Permanganate in four hours, by		
	Crude Liquor.	After Treatment on	
		Coarse Bed.	Fine Bed.
General tan water	13·05	7·11	2·77
Tan water mixed with tan liquor, after passing through four settling tanks	13·33	6·11	2·50
Tan water, mixed with tan liquor, and all soaks and washings, &c. as it leaves the works	29·90	13·70	—
Alkaline sewage, mixed with tan water	4·44	1·90	0·60
Iron liquor (wet copper process)	35·00	22·50	11·25
Strongly acid sewage, mixed with iron liquor	1·40	2·40	0·80
Refuse from milk factory	5·46	4·79	3·43
Ditto ditto	12·83	12·28	7·31
Margarine factory refuse	54·50	40·60	13·05

The publication of these results in the First Edition of the present work naturally called attention to one of the most vexed questions of the day, as the purification of waste factory refuse had hitherto been carried out only with considerable difficulty and expense. It was often contended that the sewage of particular places was difficult to treat because of certain refuse liquors contained in it. This is true to a certain extent, but not to that hitherto supposed. Excessive quantities of wool scouring form perhaps one of the most *expensive* to deal with—difficult is not the proper word to

use. It is a question of expense solely. Excessive quantities of acid iron liquor and alkali waste perhaps come next in order in regard to the expense of their treatment, but when these two liquors can be sent into the same tank for treatment they neutralise each other, and if the wool-scouring can be sent to join them, the mutual reaction will go a long way to settle the difficulty. For instance, acid iron liquor is particularly good for wool-scouring refuse and many other sewages containing large proportions of organic *débris*, and it has been largely employed for purifying ordinary sewage, especially in conjunction with an alkali, such as lime, and many methods of sewage treatment have these two substances for their base. If alkali waste, containing sulphides, is treated with iron liquor, the iron immediately combines with the sulphur, and on subsequent exposure to air part of the sulphur is set free in a harmless form, and some of the iron returns to a state of oxidation, ready to take up a further quantity of sulphur, in the well-known manner of the oxide of iron in the purifiers commonly used on a gas works. It is therefore clear, that if the conditions of a given case are carefully studied, there is every probability that a satisfactory conclusion will be arrived at. The effect of free chlorine is perhaps one of the most difficult to deal with, but even here experience of the past will guide us. In 1887, as already recited (see p. 25), large quantities of chloride of lime were used to prevent noxious emanations from the River Thames, which was at that time actually converted unintentionally into a "septic tank" at the points opposite the two outfalls at Barking Creek and Crossness. The effect at first was to retard the putrefactive decomposition of the sewage; but after a short time, as the immediate effect of the chlorine slackened, a peculiarly nasty odour was caused which was far more objectionable even than the products of the ordinary anaërobic action. A similar process has been observed by

Mr. William Naylor, who found * that "where, as in print-works waste, colour-shop waste, distillery waste, or strong brewery waste, starch products were dealt with, a 'souring' took place which very soon impaired the usefulness of the filter. In the last three waste liquors an acid fermentation is set up spontaneously (due largely to a lactic acid ferment), which actually continues during the sprinkling of the filter."

Mr. Naylor found that this souring was prevented by the introduction of the anaërobic bacteria of putrid sewage, and records the following interesting experiment: "About 20 lbs. of starch were mixed with 10 gallons of hot water, forming a paste. Half of this was mixed with one gallon of putrid sewage sludge, and, after having been left standing for one day, examined. After the expiration of five days a further sample was examined, and then the mixture was passed through the filter—repeated up to five times, the operation extending over two working days . . ." with the result that an almost complete decomposition of the starch was effected. "The other portion of the starch-paste had now become sour and stinking, though otherwise thick, slimy, and grey as at first, and was passed into the filter; but up to the twenty-first filtration a satisfactory effluent was not obtained, and the activity of the filter was impaired, if not destroyed. The effluent was turbid, soured on standing, and gave a blue coloration with iodine, indicative of unchanged starch."

Similar experiments were made with "Kier liquor," produced by boiling raw cloth, first with lime and afterwards with soda. "Eight parts of 'Kier liquor' were mixed with one part of wet sewage sludge, and were allowed to stand for

* "The Bacterial Treatment of Trades Waste," Proceedings Inst. C. E., vol. cxlvii., 19th Nov. 1901.

one week, when the only noticeable change was a reduction in the alkalinity. But after being sprinkled three times over a three-foot filter of broken clinker, previously brought into condition by sewage, the change was remarkable, the albuminoid ammonia being reduced to nearly one-quarter, and the effluent becoming clear and neutral in reaction."

As a result of these experiments, an installation was erected on the works of Messrs. Peel, Tootal & Co., of Baxenden, in whose works the processes consist of boiling grey cotton cloth, first with lime and afterwards with soda, followed by an acid wash, then a chlorine bath, and washings. The refuse also contains dye. The capacity of the tanks is equal to three days' flow. "When the plant was first put into operation about four tons of old sewage-sludge was delivered into the tanks. In about four days the mass became putrid, the ordinary liquors were introduced, and the filter was fed. To maintain putridity, sewage-sludge was added from time to time. As is the case with all bacterial filters provided with sprinklers, a small amount of suspended matter is delivered with the final effluent, but in this case it is intercepted by a small sand filter. The working of the plant has been most satisfactory. The effluent is clear and colorless, in spite of the raw liquors, varying from a deep purple to a chrome yellow. It is sweet, neutral, contains nitrates and little albuminoid ammonia, and the effect of the antiseptic free chlorine is nowhere observed. The filter is quite active bacterially, and treats successfully 350 gallons per square yard."

Mr. Naylor has successfully applied this method to various other trades-refuse liquors.

An interesting experience with a sewage containing an excessive quantity of brewery refuse was obtained in connection with the works at Worcester Park, Surrey, on which is treated the sewage from Cheam and Cuddington. When

the mixed sewage and brewery waste was treated in the existing precipitation tanks with sulphate of alumina, and the effluent discharged on to the land, a most objectionable effluvia arose, and the effluent was so bad that two actions for injunctions were threatened. At the request of the Committee of the Epsom Rural District Council, I took entire control of the works, and having a perfectly free hand, I at once stopped the use of the alumina and turned the sewage on to the land, previously stopping up the outlet valves so as to ensure the land, a stiff clay, becoming thoroughly soaked with the sewage. When this was the case, which took about three days, the sewage was turned on to a second plot similarly treated, and these two plots were able to treat the sewage for a time sufficient to enable the first rough bacteria beds to be got to work. The result was that the whole of the nuisance was at once abated, and a very fair effluent obtained. This, however, could only be effected during dry weather, and the bacteria beds were pushed on with. When these were completed the existing precipitation tanks were used as "septic tanks" in order to see whether they would assist the beds in dealing with the brewery refuse. The result was that the sour fermentation previously obtained when the sulphate of alumina was used, recurred, and the beds were unable to produce an effluent at all comparable to that yielded when the sewage and brewery refuse ran straight on to them in a fresh condition. Accordingly the tanks were put out of use. Some two years later the brewery in question ceased work, and the experiment was tried again with the tanks to save the beds as far as possible, with the result that, although a foul effluvia escaped from the tanks, the surface of the beds was undoubtedly kept cleaner, but there was no souring such as took place with the brewery refuse. The inference is clear that when such refuse has to be purified the maximum possible degree of aëration should be secured.

CHAPTER XI.

SCREENING.

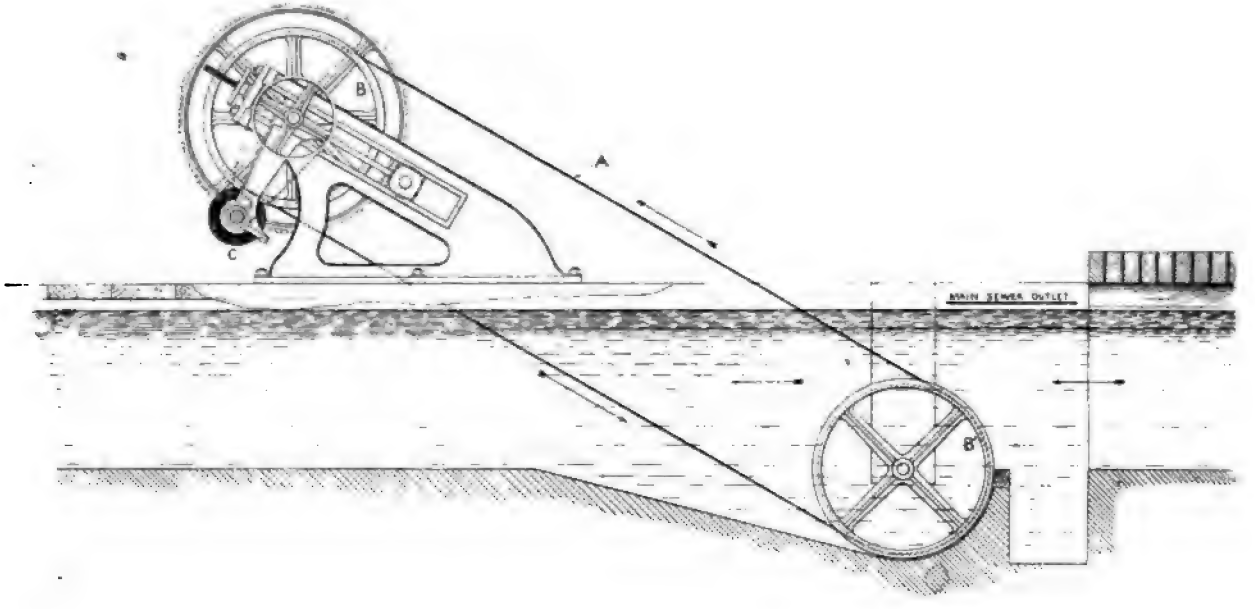
In Chapter X. of the First Edition of the present work, which contained suggestions for sewage works conducted on biological principles, it was pointed out that where the open bacteria beds are alone employed it was desirable that the sewage should be submitted to a preliminary process of screening through a self-cleansing mesh, sufficiently fine to collect the fibres of paper, &c.

The first experiments at Sutton were instituted in conjunction with hand screening alone. Whilst the work of the bacterial treatment of the crude sewage was confined to the first bed constructed, the necessity for screening was limited; but as soon as the success of the system became established, and larger quantities of the sewage were treated by the additional beds constructed in the old precipitation tanks, it became obvious that the screening must be carried on by a self-acting contrivance if the labour bill was to be kept down.

Messrs. John Smith & Co., engineers, Grove Iron Works, Carshalton, Surrey, have introduced a very useful self-acting screen, which consists of an endless band of perforated metal, A., carried on two cylinders, B., B., which are adjustable for taking up any slack in the band.

The upper cylinder is caused to revolve by means of a small motor, by preference a water-wheel, driven by the flow of the sewage itself; but where this is not practicable the motive power can be derived from a line of shafting, or any other

SIDE VIEW OF SELF-CLEANSING AUTOMATIC SCREEN.



To face p. 200.]

CHAPTER XII.

THE PURIFICATION OF THE THAMES.

Many persons still living remember the condition of the river Thames before 1855, when the Metropolitan Board of Works was constituted for the express purpose of putting an end to the state of things that prevailed at that time. The history of the work which has resulted in effecting the great improvement which has taken place in the river has never yet been written in its entirety, the story being wrapped up in numerous official reports, and in papers which have been read from time to time before various societies. A complete work upon the subject would involve numerous extracts from these, and I therefore propose to indicate only in outline the chief points, naturally giving prominence to the method of treating the sewage at the two outfalls.

Of all the evils from which London suffered, the most manifest and the most detrimental to the health and well-being of the inhabitants was the extremely defective sewerage system, and with this the accompanying evil that all the filth of the vast metropolitan population was poured into the river in the very midst of the most populous quarters. The sewers were under the control of Commissioners appointed for the purpose by the Crown. They were originally intended to carry off only rain water from the streets, the open ground, and the roofs of houses. But upon the compulsory abolition of cesspools, which was effected by the Metropolitan

Commissioners of Sewers under the provisions of the Act of the year 1848, the sewers became the vehicle for carrying into the river all the excreta and waste water of the population. Most of the sewers, having to pass under the low grounds on the margin of the river, discharged their contents at, or about, the low-water level, and at the time of low water only. As the tide rose it closed the outlets, and thus the sewage flowing from the high grounds accumulated in the low-lying portions of the sewers, where it remained stagnant in many cases for eighteen out of the twenty-four hours. During this stagnation the heavier ingredients fell to the bottom, and from day to day accumulated in the sewers; besides which, in times of heavy and long-continued rain, and more particularly when much rain fell at the time of high water in the river, the closed sewers were unable to store the increased volume of sewage water, which thus rose through the house drains and flooded the basements of the houses.

The mischief caused by emptying the sewers into the Thames in the middle of London was of course intensified by the circumstance of the discharge taking place at the time of low water only. The sewage was carried by the rising tide up the river to be brought back to London by the falling ebb tide, there to mix with each day's additional supply, the progress of many days' accumulation towards the sea being almost imperceptible except in periods of heavy flood. Moreover, the small volume of water in the river at low water was quite incapable of effectually diluting and neutralising the offensiveness of the vast quantity of sewage poured into it. Thus were the Thames and its tributaries turned into open "septic tanks," and the broader reaches of the river as it then was, such as that between Westminster and Waterloo Bridges, had their banks covered with accumulations of offensive mud, which was exposed at low water, and in warm

weather, under the influence of the sun, gave forth exhalations of a most objectionable character.

In consequence of this state of things, a Royal Commission, appointed in 1853 to inquire into the state of the Corporation of the City of London, recommended the division of the metropolis into municipal districts, and the creation of the Metropolitan Board of Works as the central body, the members of which should be elected by the Boards or Councils of the several districts, including the City. This central body they thought should be entrusted with the management of public works in which all parts of the metropolis had a common interest. It will be understood that there were many functions entrusted to this body which need not here be mentioned, as our express object is that of the purification of the Thames, and we need not dwell on questions of purely political aspect.

The Metropolitan Board of Works thus created, as soon as possible after its formation, applied itself to the consideration of what was undoubtedly the most important question with which it had to deal, namely, the improvement of the sewerage system and the diversion of the sewage from the Thames as it flowed through London. The main objects to be attained were the interception (so far as practicable by gravitation) of the sewage, and of so much of the rainfall with it as could be reasonably dealt with, and its conveyance to points of discharge at some distance down the river below London; the substitution of constant instead of intermittent flow in the sewers; the abolition of stagnant and tide-locked sewers, with their consequent accumulation of deposited matters; and the substitution of deeper and better sewers, with improved outfalls.

After the usual debates amongst various authorities, which are now of only historical interest, the Board proceeded with the construction of the present main drainage system. For

this purpose three main intercepting sewers were constructed on each side of the river, and termed respectively the high-level, the middle-level, and the low-level sewers. The high and middle-level sewers on the north side of the Thames discharged by gravitation, but the low-level sewers discharged only by the aid of pumps. The three intercepting sewers were made to converge and unite at Abbey Mills, West Ham, where the contents of the low-level sewers are pumped up to a higher level, and the aggregate stream of sewage flows through the northern outfall sewer to Barking Creek, and then into the river by gravitation.

On the southern side of the Thames the three intercepting sewers were made to unite at Deptford Creek, where the sewage from the low level is pumped to the higher level, and the united stream flows in one channel through Woolwich to Crossness, where it is pumped into reservoirs, and thence flows into the river. The greater part of these works was completed by the year 1864, in which year sewage began to flow into the river at Barking Creek, and in 1865 the works on the south side of the river at Crossness were opened by H.R.H. the then Prince of Wales.

The following short statistics will convey some idea of the magnitude of these main drainage works:—

North Side of the Thames.

Sewer.	Length. Miles.	Diameter.
Northern high-level sewer.....	7½	from 4 ft. to 9½ ft. by 12 ft.
Northern middle-level sewer....	9½	from 4½ ft. by 3 ft. to 10½ ft.
Piccadilly branches.....	2¾	
Northern low-level sewer	8¼	from 6¾ ft. to 10¼ ft.
Hackney branch	2½	
Isle of Dogs branch	1⅞	
Western sewers, main line.....	5⅓	from 4 ft. by 2 ft. to 5 ft.
Fulham branch	1⅓	
Acton line	1⅜	
Northern outfall sewer	5½	three culverts each 9 ft. in diameter.

South Side of the Thames.

Sewer.	Length. Miles.	Diameter.
Southern high-level sewer.....	5⅝	from 4½ ft. by 3 ft. to 10½ ft.
Effra branches	7¼	from 7 ft. to 10½ ft.
Southern low-level sewer	9½	from 4 ft. to two culverts each of 7 ft.
Bermondsey branch.....	2¾	from 5 ft. to 5½ ft.
Southern outfall sewer	7½	11½ ft.

Pumping stations:—Abbey Mills, eight engines; Crossness, four engines; Deptford, four engines; Pimlico, four engines.

The total length of the main intercepting sewers was thus about 82 miles; they were capable of intercepting daily 63 million cubic feet, or nearly 400 million gallons of sewage, and the total cost of the works was about 4,600,000*l.* The average daily quantity of sewage discharged is over 200 million gallons.

So far all went well for a time, the river as it flowed through London no longer showed signs of pollution, where before it was a mass of stagnant corruption, and it appeared for a time that the alteration in the discharge by sending it into the river twelve miles below London Bridge, at Crossness and Barking Creek at high water, instead of in London itself at low water, would effectually prevent all further cause of nuisance. Ten years after the opening of these works, however, it appeared that certain signs were not wanting that the river was being over-taxed, and it was seen that instead of the discharge being confined to the first part of the ebb-tide, as originally intended, it was extended over several hours in consequence of the increased volume of water which had to be dealt with, and which could not be retained in the storage reservoirs for a sufficient length of time, and therefore overflowed into the river before the time of high water. The result was to repeat to a large extent the experience of years before when the sewage ran into the river at low water, as part of the sewage was thus carried by the tide to the upper

reaches instead of being carried down into the larger volume of water in the lower reaches, and in hot and dry weather the full purifying power of the river could not be utilised. So marked was the effect which was brought about by the increased number of intercepting sewers constructed from time to time to prevent flooding in many parts of the metropolis in response to the demands of various districts, as the effect of previous work became more and more marked, that in 1882 a Royal Commission, with the late Lord Bramwell as its chairman, was appointed "to inquire into and report upon the system under which the sewage is discharged into the Thames by the Metropolitan Board of Works; whether any evil effects resulted therefrom; and, in that case, what measures could be applied for remedying and preventing the same."

As a result of their inquiries the Commissioners reported that the London sewage ought not to be discharged in its crude state into any part of the Thames; that the solid matters should be separated from the liquid by some process of deposition or precipitation, and should be applied to the raising of low-lying ground, or burnt, or dug into land, or carried away to sea. That the liquid portion of the sewage remaining after precipitation might, as a temporary measure, be then allowed to pass into the river. *That its discharge should be rigorously limited to the period between high water and half-ebb of each tide.*

In consequence of this decision, which was in accordance with the evidence I had the honour to submit to the Commissioners, as the outcome of the results of a large number of experiments carried out by Sir Joseph Bazalgette, Dr. Dupré, and myself, on the London sewage, for the express purpose of submitting them in evidence before the Commissioners, who were kind enough to listen to my suggestions with the most encouraging attention, the Metropolitan Board pro-

ceeded to make further trials for the purpose of obtaining definite information before constructing the works on a sufficiently large scale. As a result of these, in January the Board entered into a contract for the construction of the Northern Outfall Precipitation Works at Barking Creek at a cost of £406,000; and followed this action by another contract in May, 1888, for similar works for the southern side at Crossness at a cost of £259,816.

As it had been decided to adopt the system of carrying the solid matters precipitated from the sewage to sea, a trial vessel was obtained from the Barrow Shipbuilding Company in 1887 at a cost of £16,353. This vessel was the outcome of competitive plans, and has been found to do its work in a most admirable manner, as also have the five additional vessels constructed on the same pattern, which form the present fleet of six steamers, each having a tonnage of 1,000 tons; the additional five costing, however, from £24,000 to £26,000 each.

In general design these vessels may be described as consisting of four oblong tanks, viz., two aft and two forward, having a floatage space between them and the bottom of the vessel, with engines and twin-screws to drive them. When the vessel is unloaded the bottom of these tanks is 6 in. above the surface of the water, as also is the top of the sludge when the tanks are full. When the outlet valves at the bottom of the tanks are opened by means of screws worked from the deck, the vessel rises until the tanks are empty. When the valves are fully opened the whole cargo of 1,000 tons can be discharged in about seven minutes.

In consequence of numerous inquiries as to the plan which the late Metropolitan Board of Works decided upon adopting, and in response to a request from the Institution of Civil Engineers, I submitted the outlines of the method and the reasons for them to that body in a paper read in January, 1887.

SLUDGE SHIP LOADED.

[*To face p.* 208 (*No.* 1).

SLUDGE SHIP RETURNING EMPTY.

[*To face p.* 208 (*No.* 2).

In this paper I drew attention to the following points:—

(1) Detrimental effect of an excess of chemicals.
(2) The limited reduction of the organic matters in solution by chemical treatment.
(3) The use of iron salts as an auxiliary to lime when necessary.
(4) The action of bacteria in completing the process of purification.
(5) The objection to filtration of crude sewage on the lines as then understood.
(6) Final purification of the effluent by proper filtration through land.
(7) Subsidiary treatment of effluent when necessary.
(8) Aëration as an aid to bacterial life.
(9) Disposal of the solids.

As already mentioned, the method adopted by the Board was first submitted to the Royal Commissioners by myself in 1884, and the following extract from that evidence will clearly indicate the position as it then stood:—

"We found that whatever process might be used which could be applied in practice would have but a very slight effect in removing the dissolved organic matter. Then we came to the conclusion that the only effect which might be expected would be the removal of the suspended matters, and that we might neglect for this purpose the whole of the dissolved matters. Proceeding with our experiments we found that the use of four grains of lime and one grain of protosulphate of iron was sufficient practically to remove the whole of the suspended matter and the grosser part of the offensive odours. In fact, we were satisfied that it would do all that was required to be done with the London sewage at Barking and Crossness, and that the effluent, if discharged into the Thames there, would certainly be hardly noticeable;

and by the time it was thoroughly diluted with river water it would be to all intents and purposes invisible; and that all effect of the sewage in the river in point of appearance would be annihilated. The matters in solution in the sewage would still be there; but the matters in solution are those which are more readily oxidised by the action of the river, and so would disappear at a much greater rate than they do at present."

As will be seen from the foregoing summary of the report of the Commissioners, they agreed with these views, but with the following proviso:—"10. But we believe that the liquid, so separated, would not be sufficiently free from noxious matters to allow of its being discharged at the present outfalls as a *permanent* measure. It would require further purification, and this, according to the present (1884) state of knowledge, can only be done effectually by its application to land."

This safety clause, as it may be called, is now fully met by the results of the experiments already described in Chapter V., and which can be put into practice on the whole of the London sewage whenever it may be deemed to be necessary.

The sewage north of the Thames is delivered at the Northern Outfall by three 9-ft. sewers. After passing the screens it receives its proper quantity of lime, which varies with the strength and rate of flow of the sewage. At the liming station the lime, after being weighed as it is taken from the store, is placed in large mixing trays 15 ft. in diameter, fitted with four revolving arms, to each of which a heavy rake is suspended. Sufficient water is then let into the tray to slake the lime. This being accomplished, more water is added and the mixing-arms are rotated by steam power, the lime and water being thus stirred into a cream as dilute as possible. Water is continually admitted and the

LIME STIRRERS, NORTHERN OUTFALL, BARKING CREEK.

[*To face p.* 211.

cream of lime flows out into a channel leading to the lime-water tanks, where it meets a large access of water, and is thereby diluted and carried into the tanks, six in number, each having a capacity of about 100,000 gallons. The mixture of the lime and water is further facilitated by the fall from the trough into the tank, and thus the whole bulk is kept in agitation until the tank is full. The lime water so obtained is forced by centrifugal pumps to an overhead tank placed on the top of the boiler house and lime store, whence it is drawn off as required. At first the lime water was made with crude sewage and the top liquor drawn from the sludge-settling channels; but the extent to which the lime is destroyed by these was so great that they have been replaced at Crossness by river water.

After receiving the lime, which at Crossness is entirely in solution, as originally intended, the sewage passes the iron-water station where the solution of iron sulphate is added. No special mixing arrangement is applied, as the rolling motion of the sewage as it passes along the sewer is found to answer the purpose. The iron salt is dissolved in a tank of water heated by a steam coil, and the concentrated solution thus obtained is sufficiently diluted and passed direct into the sewer containing the already limed sewage. The precipitation effected by the combined action of the lime and iron is completed in thirteen precipitation channels.

The method of discharging the sludge from the precipitation channels to the sludge-settling channels is by sweeping the deposit obtained from the action of precipitation through culverts leading under the main sewer to the receiving-chamber at the engine house, whence it is pumped into the settling channels. On its way to these the sludge is again passed through gratings to collect rags, &c. which may have escaped the first filth gratings. The quantity of solid matter extracted by the combined action of the double set of gratings

is between 80 and 100 tons per week. A destructor furnace is built close to the filth hoist, or first set of gratings, and is used for calcination of the refuse.

The following are the results of an analysis of a sample of this refuse :—

TABLE XLIII.

Analysis of Filth from Gratings at the Northern Outfall.

		Per cent.
Moisture		77·2
Wood		1·0
Coarse string and fibre		0·7
Coarse rags		0·4
Fine rags, pulp, &c.		16·6
Very fine fibrous matters, sand, earthy matter, &c., containing volatile organic matter, of which one-fiftieth is nitrogen	51·5	
Phosphoric acid	2·6	4·1
Sand, earthy matter, &c.	42·2	
Moisture	3·7	
	100·0	100·0

The amount of nitrogen in the fine fibrous and earthy matter is only 0·041 per cent., and of phosphoric acid 0·11 per cent. of the whole. Its manurial value is therefore but slight.

After the sludge has settled and the top water has been drawn off by means of sliding penstocks, the sludge is let into the storage tanks under the settling channels, whence it is forced by direct-acting pumps to the ships. Formerly the water drawn from the settled sludge was pumped to the liming station, but alterations have been made which enable this liquor to be separately treated with lime and iron, and after such treatment to settle in the sewage-precipitation channels.

The sewage of London south of the Thames is carried by an 11-ft. 6-in. sewer to Crossness. As the whole of the sewage was already screened, it was not necessary to erect an addi-

tional filth hoist as at the Northern Outfall works, except on a small scale for the sludge. The liming station is admirably suited to the requirements of the works, practically the whole of the lime being in solution before its addition to the sewage. The lime mixers at Crossness are similar to those at the Northern Outfall, and are 12 ft. in diameter. The charge of lime varies between 1 ton and 1½ tons, to meet the flow of sewage. The lime, having been formed into a cream, is discharged from the mixers into a culvert, where it meets with river water pumped for that purpose, and then through a series of tanks, six in number, each of a capacity of about 40,000 gallons. In two of these tanks a pair of Gabbott stirrers, 12 ft. in diameter, are fixed. The lime water passes first through one of the end tanks and thence over weirs into four others successively, into the lime-water culvert. The quantity of river water pumped for this purpose is between 2,500,000 gallons and 4,000,000 gallons daily. The quantity of commercial lime taken for making the lime water is about 110 grains per gallon, of which, on an average, about 70 per cent. is in solution. It will be noticed that it is necessary to employ an excess of lime to allow for the hard core, and the neutralisation of a portion of the lime by the carbonic acid in the river water employed for its slaking and solution. The iron water is made at Crossness by the simple agitation of the crystals of iron salt with water in an ordinary mixing mill from which the rollers are removed, stirring arms being substituted in their place, the effect being equally efficacious with that of the steam coil at the Northern Outfall works. The precipitation channels at Crossness are not fitted with the telescope weirs for the purpose of emptying the channels, but with the ordinary floating arms, the bulk of the effluent, however, falling over the weirs as at Barking Creek. In other respects these channels are almost identical. In consequence of the more effective arrangements for making

lime water at Crossness, the results have been much more satisfactory than those at Barking Creek. The method of collecting the sludge, settling it, and loading the ships is identical with that at the Northern Outfall works.

The fleet of vessels, each capable of carrying about 1,000 tons, employed for the purpose, carried to sea during the year 1894, 2,052 cargoes of sludge, of which quantity 1,380 cargoes, containing 90·7 per cent. of moisture, were conveyed from the Northern Outfall, and 724 cargoes, containing 91·25 per cent. of moisture, from the Southern Outfall. The discharge takes place in the Barrow Deep, commencing at a point ten miles east of the Nore, and proceeding thence from five miles to ten miles down that channel, which is unused for traffic, being about half-way between the Swin Channel, or route for vessels proceeding north, and the Princes Channel, which is the ordinary route for vessels going south. As the sludge is discharged from the bottom of the vessel, some 10 ft. under water, and is thus agitated with the sea water by the action of the twin screws, the diffusion of the sludge in the water in the wake of the vessel is very complete, so much so that when there is but a slight ripple the visible effect of the sludge is lost after a few minutes. The sand and earthy matters soon separate by subsidence, and the animal and vegetable *débris* is rapidly consumed by the organic life in the sea water. This is evidenced by the fact that, although over 20,000,000 tons of sludge have now been deposited in this part of the estuary, the most careful microscopical examination and chemical analysis fail to detect more than the merest trace of the mineral portion of the sludge, either in dredgings from the bottom of the channels or on the surface of the sandbanks, which are now as clean as in 1888, before more than a few trial cargoes had been discharged. The cost of this operation has been found to work out to about 4¼*d.* per ton of sludge.

TABLE XLIIIA.—*Sewage Precipita of Se*

Each daily sample was from a mixtu

1894. Month.	Analysis of Average Sewage. Grains per Gallon.				
	Total suspended Matters.	Total dissolved Solids.	Chlorine.	Oxygen absorbed from Permanganate in 4 Hours.	A
					Free.
January ..	31·5	60·0	9·4	3·396	2·80
February ..	28·3	58·4	8·2	3·415	2·94
March	28·3	54·8	8·4	3·283	3·24
April	28·8	53·0	8·7	3·172	3·24
May	36·9	52·2	10·1	3·269	3·36
June	25·7	59·0	10·2	2·924	3·21
July	28·8	63·0	13·3	3 013	2·87
August....	31·3	62·2	14·1	2·814	2·62
September .	25·5	65·2	15·5	2·856	3·00
October ..	34·6	69·6	17·8	3·221	3·33
November ..	27·2	63·8	9·3	2·942	2·70
December ..	31·1	61·5	8·8	3·186	2·94
Average ..	29·8	60·2	11·1	3·124	3·02
January ..	38·1	84·8	20·4	3·418	2·55
February ..	30·2	79·1	17·3	3·474	2·38
March	29·5	81·5	17·9	4·050	3·55
April	30·2	82·1	20·5	3·658	2·42
May	33·5	113·2	37·3	3·614	2·69
June	30·6	86·4	26·4	3·952	3·35
July	36·1	93·7	29·5	3·721	2·79
August....	36·1	81·5	34·5	3·554	2·68
September .	26·6	118·6	37·8	3·799	5·72
October ..	35·3	113·8	30·3	3·951	2·56
November ..	22·5	79·1	14·2	3·420	2·40
December ..	29·1	76·3	12·2	3·892	2·43
Average ..	31·5	90·8	24·8	3	

Monthly Averages of Daily Analyses ffluent.

les taken every two hours day and night.

	Analysis of Average Effluent. Grains per Gallon.					
	Total suspended Matters.	Total dissolved Solids.	Chlorine.	Oxygen absorbed from Permanganate in 4 Hours.	Ammonia.	
					Free.	Albuminoid.
ırn Outfall.						
	8·6	62·6	9·4	3·284	2·713	0·351
	7·1	60·9	7·9	3·389	2·658	0·358
	7·7	59·8	8·3	3·441	3·358	0·368
	8·2	58·8	9·3	3·516	3·572	0·362
	8·3	61·3	9·8	3·506	3·598	0·361
	6·0	59·6	9·9	3·070	3·189	0·330
	6·1	64·2	12·5	3·004	3·024	0·334
	7·1	63·7	13·2	2·968	2·838	0·324
	5·1	65·5	14·3	2·944	3·442	0·328
	7·4	70·3	16·1	3·202	3·524	0·428
	6·1	66·3	9·1	3·024	2·696	0·343
	7·6	65·2	8·9	3·360	3·031	0·386
	7·1	63·2	10·8	3·225	3·137	0·356
ırn Outfall.						
	8·9	85·7	22·3	2·910	2·261	0·294
	6·1	81·6	19·3	3·268	2·431	0·299
	7·8	83·1	20·8	3·492	2·479	0·348
	7·2	87·6	26·0	3·253	2·316	0·359
	7·1	109·1	34·2	3·330	2·545	0·397
	6·3	100·8	33·1	3·122	2·731	0·408
	6·6	130·3	45·8	3·324	2·768	0·389
	6·1	120·4	41·9	3·036	2·539	0·335
	5·7	119·2	37·7	3·089	2·880	0·402
	5·0	128·6	36·7	2·925	2·425	0·306
	3·2	76·4	12·9	2·758	2·001	0·197
	5·0	68·1	10·5	2·876	2·140	0·240
	6·2	99·2	28·4	3·115	2·460	0·331

[*To face page* 115.

Character of Sewage and Effluent.—The effect of the general desire to lessen the pollution of the Thames by refuse from manufactories has been largely to increase the quantity of foul matters received at the outfalls, and this has necessitated careful watching. In almost every case, however, it has been satisfactory to find that such increases in the pollutive matters have been fully met by the treatment adopted. The average character of the sewage before and after treatment is set out in Table XLIIIA. opposite, showing the monthly averages of the daily analyses of samples taken every two hours, day and night, at each outfall, during the year 1894. These include storm water, which increases the average amount of suspended matters left in the effluent, as in many instances the quantity found in the dry weather sewage is considerably lower. It will be seen that at Crossness, in consequence of the better solution of the lime water, there is a material reduction of the matters held in solution, the oxygen absorbed from permanganate in four hours being reduced from 3·7 to 3·1 grains per gallon, or 16 per cent., a result which agrees closely with the preliminary laboratory experiments.

At the Northern Outfall the results are not so good. By analyses it is shown that the average quantity of suspended matters in the sewage at the Southern Outfall was 31·5 grains per gallon, and at the Northern Outfall 29·8 grains per gallon; results which agree very closely with the quantities determined in 1883, and given in evidence before Lord Bramwell's Commission, with the exception that the former is now somewhat stronger than at that date. The average results then found over a period of three months were, Southern 26·26 grains per gallon; Northern 29·1 grains per gallon. Having regard to all the circumstances, it would probably be difficult to obtain a closer agreement, especially when it is considered that the actual quantity of sludge obtained as measured in the sludge stores, after correction for

quantity and effect of the chemicals used, moisture and matters left in the effluent, agrees with the above results within a fraction of a grain.

Cost.—In a report to the late Metropolitan Board of Works, on the 24th November, 1884, by Sir Joseph Bazalgette and myself, an estimate for the precipitation of 162,500,000 gallons of sewage at the present outfalls was submitted as follows:—

TABLE XLIV.

Chemicals	£22,000
Barging to sea	37,200
Labour and pumping	26,300
	£85,500
10 per cent. contingencies	8,500
If effluent is treated with about four tons of manganate per day for three months in the year	6,000
	£100,000

First outlay (estimated), £1,140,000, including £131,000 for barges.

The manganate has not been found essential, as was originally suggested, and was provided for only as a safeguard. The working expenses are thus reduced to £94,000, which, with interest on capital at 3 per cent., or £34,200, equals a total of £128,200 per annum.

The following are the figures actually obtained in practice during the year 1894:—

TABLE XLV.

Working expenses (including chemicals, &c.), for precipitation	£71,119
Barging to sea	30,212
	£101,331
Interest on capital	25,400
	£126,731

First outlay (capital), £932,000.

This close approximation to the estimate of 1884, especially considering the difference in the daily volume of sewage then

taken into account, viz., 162,500,000 gallons, as against the volume in 1894, viz., 203,000,000 gallons, may be regarded as satisfactory. If the estimated working expenses, viz., £85,500, are increased proportionately to the volume of sewage, the original estimate will be raised to £106,800 as against the actual cost of £101,331. These figures, coupled with the results obtained, speak for themselves as to the wisdom of the action of the late Board with reference to the question of the treatment of the sewage of London.

It will be of interest to note that as a rate of $\frac{1}{4}d.$ in the pound produces £35,320 per annum, the cost of working is less than a rate of $\frac{3}{4}d.$ in the pound, or, including the repayment of loan and interest on capital, only a fraction over 1*d.* in the pound. In comparison with this result of a capital expenditure of £932,000, and a working expense of only £101,331 per annum, it may be of interest to shortly glance at some of the alternative proposals which have been made for dealing with the sewage of London. One proposal was to remove the outfalls to Hole Haven, below Gravesend, at a first cost of £4,000,000 sterling, there to erect the necessary works and precipitate as at present. This, it will be seen, would have involved a first outlay of about £5,000,000 sterling. Another, very strongly and influentially supported, was to expend £12,000,000 sterling and carry the sewage to the Maplin Sands. Again, another authoritative opinion, expressly invited by the present London County Council, was to the effect that in the event of the present scheme proving unsuccessful, the next alternative would involve an outlay of £8,000,000 sterling. Many other proposals for the chemical treatment of the sewage alone, or in combination with extensive farming operations, have been made from time to time, the lowest estimate for which involved an annual cost of double that of the present scheme.

It will thus be seen that on financial grounds alone the

adoption of the system which I had the honour of submitting to Lord Bramwell's Commission in 1884 has been of vast benefit to the ratepayers of the metropolis; in addition to which the information on the general question of sewage treatment which that system has been the means of disseminating throughout the country, has enabled alterations to be made on large numbers of sewage works, resulting in greater efficiency and considerable economy, to the advancement of better sanitation and the relief of the public purse.

The improvement in the state of the river since the opening of the outfalls in 1890-2 has been so great that many observers have evinced surprise that such results could have been achieved by such apparently simple means. The secret, if secret there be, lies solely in the fact that while the addition to the sewage of certain purifying agents was evident to ordinary observation, the invisible but far more potent action of the bacteria, already in the sewage and in the river water, to destroy the organic matters remaining after chemical treatment was not so evident; and thus, although I clearly indicated their action in 1887, their work has been overlooked by the majority who largely judge by external appearances.

Although the methods described above have effectually put a stop to the former distressing condition of the river, the effect of the improved state of the water is still inimical to fish life. My forecast that improvement in our knowledge in the future would doubtless enable us to complete the tentative process of precipitation, and enable us thereby to send a really purified effluent into the river, has come true. From the earlier chapters of the present work it will have been seen that the process of treating the sewage effluent on bacteria beds will suffice to secure the quality of the Thames water in the lower reaches being at all times capable of supporting fish life.

From the accompanying diagrams, showing the results of the examination of the river Thames from Teddington to the Nore which was carried out under my direction in 1893-4, it will be seen (Diagram J) that the dissolved oxygen in the river water at Teddington fell to 70 per cent. of the total possible quantity on only one occasion, whilst the general average was about 85 per cent. From Diagram K it will be seen that at London Bridge the dissolved oxygen at high water fell to as low as only 10 per cent.; whilst Diagram L shows that at Southend at low water in the height of summer it fell to 60 per cent.

From these results, culled from a large number of similar series, it is clear that there is a long stretch of water between Teddington and the lowest reaches which contains such a small quantity of gaseous oxygen as to render it incapable of supporting fish life. On turning to Diagram M, it will be seen that the area of maximum pollution varies in position, according to the season, from Hammersmith in the summer months to below Barking in March, its position being due to the influence of the rainfall. As will be seen from the broken black line, the quantity of water coming down the river at Teddington Weir varied greatly. The less the upland water, the higher up the river the area of maximum impurity travelled, and *vice versâ*.

A very prolonged series of observations on the Thames, extending over nearly a quarter of a century, has shown that when the percentage of aëration, indicated by the "dissolved oxygen," falls below fifty, there is very little chance of fish thriving in the water; and that when it falls below thirty, it is certain that no fish can sustain life for any prolonged period. From the foregoing it will be seen that it is impossible to imagine that the reaches of the Thames below lock and above, say, Erith can ever again support a healthy fishery until a still further improvement takes place by the

adoption of the bacterial principle for the final purification of the effluent derived from the sewage of London at Barking Creek and Crossness. I candidly confess that I look forward to the adoption of the coke-breeze bed system, which I worked out at Barking Creek—as described in Chapter IV. —as the coping stone of my life's work in effecting the purification of the Thames.

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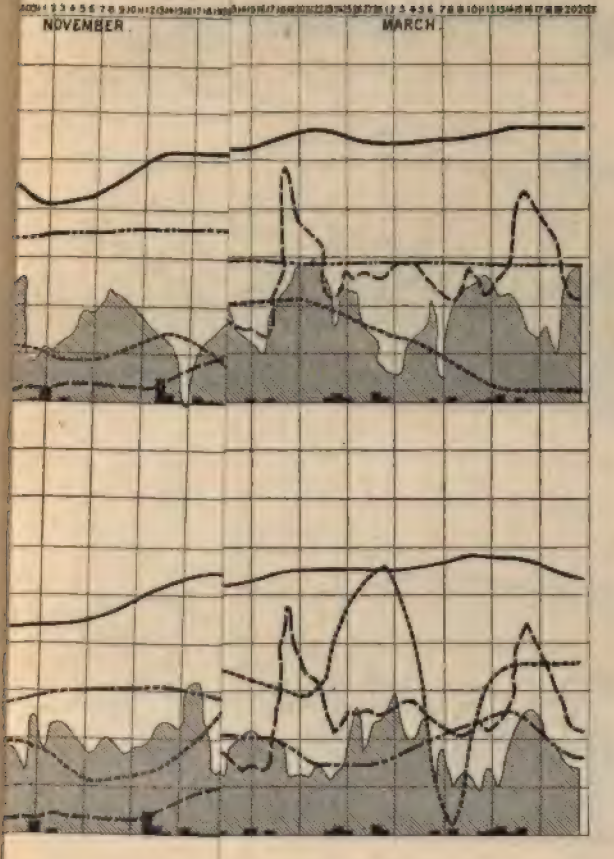


CHAPTER XIII.

THE DISCHARGE OF SEWAGE INTO SEA-WATER.

One of the favourite methods of disposing of sewage when possible is its discharge into sea-water, on the assumption that the enormous dilution effected would speedily bring about its disintegration and destruction. This is one of those cases in which the maxim "out of sight out of mind" was thought to have special application; and, in consequence, the universally considered panacea for the sewage difficulty at seaside towns was to run an outfall sewer as far as convenient out into the sea and to discharge the sewage at such time of the tide as was thought would effectually carry it away. The result, however, in many cases has not been all that was desired. In some instances the flow of the tide has brought the sewage back to the point of departure, and in some cases right into the stretch of water used for bathing, so that visitors have had to postpone their "dip" until the unsightly flood has drifted further on. Not only has this objectionable feature been the result of the system, but in one instance I have in mind a large ventilating shaft on the outfall sewer has been erected on the beach, with a series of steps leading right up to the top, with the result that this made an excellent "coign of vantage" for children who climbed up to the top and sat on the grating, thus mixing their seaside breeze with the emanations from the sewage below them. The result of this elementary method of disposal, however, is now known not

to cease here. In a large number of instances the sewage discharged finds its way to various oyster, mussel, or cockle beds, and it is now well established that the effect of this has been to cause typhoid fever to many of those who have partaken of such infected food.

This question has received much attention, particularly from Dr. Arthur Newsholme, Medical Officer of Health for Brighton, who in his report to that borough in 1898 published the following admirable memorandum on the question :—

Memorandum as to the Connection between the Consumption of Shell Fish contaminated by Sewage and Infectious Disease.

By Arthur Newsholme, M.D., *Medical Officer of Health of Brighton, Examiner in State Medicine to the University of London.*

The causes of enteric fever have probably been more thoroughly investigated than those of any other single disease. It is generally recognized that the contagium of this disease is derived from the excreta of patients suffering from it, either by direct infection in connection with the nursing of patients or by indirect infection in a more remote manner. The chief indirect means by which infection may be received are as follows :—

1. Emanations from defective drainage arrangements or from a subsoil which is chronically contaminated by the typhoid organism, this organism being able to live and multiply in a sewage-contaminated subsoil.

2. Contamination of water or milk by dejecta derived from enteric fever patients.

3. Contamination of shell fish or other foods by dejecta derived from enteric fever patients.

It has been a source of disappointment to the authorities of many great towns that the provision of unpolluted drinking water, and the construction of main sewerage works and of water-tight house drains, which free the subsoil from contamination, have not been followed by so great a reduction in the mortality from enteric fever as might have been expected.

The Brighton sanitary authority have shared in this disappointment. They have entirely eliminated cases of enteric fever caused by con-

taminated water; they have had in recent years no cases traceable to contaminated milk; the majority of the house drains in the town are completely water-tight, and the subsoil is thus kept free from the contamination which favours the continued vitality of the typhoid organism within it. Notwithstanding these facts, they find that although the amount of enteric fever is low in Brighton they still suffer from more of this disease than they had reasonable grounds to expect, having regard to their large expenditure on the sanitary improvement of the town.

A considerable proportion of the cases are imported, but when these are eliminated they find that a large share (at the least 30 per cent.) of the cases originating in the municipal borough of Brighton are caused by conditions other than those mentioned under the first two headings above.

It is well known by every medical officer of health that in a considerable proportion of cases of enteric fever the source of infection remains undetected, after elimination of water or milk or defective sanitary arrangements as possible causes of infection. This remark applies particularly to the sporadic cases which, in towns under an efficient sanitary régime, form the majority of the total cases. Such cases constitute the main difficulty in completely eradicating enteric fever. It is through contamination of water or milk on a large scale from such sporadic cases that our great epidemics of enteric fever arise.

It is furthermore now becoming more generally recognised that enteric fever is much more frequently acquired from ingesta (food and drink) than by inhalation of the poison. But the cases in which difficulty in tracking the source of infection occurs being isolated items, without any connecting link with others in the same neighbourhood, it is easily understood why there has been considerable diffidence in arriving at the conclusion that such cases are caused by specifically contaminated shell fish. This cause of enteric fever has now, however, become generally recognised.

It was recognised early in 1894 by the medical officer of health of Brighton, and, as will be seen by the summary of local action hereinafter given, the subject has almost constantly been before the Brighton sanitary authority since that time. The representations made by that authority were one of the reasons leading to the appointment of a medical inspector of the Local Government Board to make a detailed inquiry into "Oyster Culture in Relation to Disease"; and Dr. Bulstrode's report, issued in October, 1896, amply confirms the isolated observations previously made. Enteric fever is not the only disease which has been traced to specifically contaminated shell fish, for, as Sir R. Thorne Thorne remarks, "In the Report on 'Cholera

in England in 1893,' which I had the honour of submitting to the Board in December, 1894, I expressed my conviction that the distribution of shell fish from Cleethorpes and Grimsby as a centre had been concerned in the diffusion of scattered cases of cholera over a somewhat wide area of England." Medical officers of health in various parts of England have also reported on cases of enteric fever traceable to the consumption of sewage-contaminated shell fish. As long ago as 1880, Sir Charles Cameron showed the "possible relation of typhoid fever to the consumption of specifically polluted oysters" in Dublin.

The contribution of Sir William Broadbent, F.R.S., to the "British Medical Journal," 1895, vol. i., p. 61; of Sir Peter Eade to the same journal, 1895, vol. i., p. 121; and numerous similar contributions show that, as attention is being increasingly drawn to this cause of enteric fever, it is becoming recognised as a not infrequent cause of sporadic cases of this disease.

The following letter from Sir William Broadbent, physician to the then Prince of Wales, is an important contribution on the subject:—

[COPY.]

"84, Brook Street,
"Grosvenor Square, London, W."
"January 21st, 1898.

"DEAR DR. NEWSHOLME,—I have read with much interest and entire approval the petition to the Local Government Board on the regulation of the supply of oysters and other shell fish for food purposes. Some years ago I published a series of cases demonstrating the causation of typhoid fever by oysters, and every year since I have seen cases in which typhoid fever has been distinctly traced to oysters; at times the form of fever has been very deadly. The investigations made by Dr. Bulstrode and others have not only furnished scientific confirmation of the clinical conclusions, but have shown that the source of contaminated oysters, &c. can be identified, and that a remedy can be applied. It seems to me, therefore, an imperative duty that some such measures as those indicated in the petition should be adopted, and I certainly support the petition. I am not sure that I can attend with the deputation, but if you will give me notice of the time and place I will make an effort to be present.

"Yours very truly,
(Signed) "W. H. BROADBENT."

Medical attention has of late been specially directed to the question of the relation between the consumption of shell fish contaminated by sewage and infectious disease.

The report of the medical officer of the Local Government Board on this subject and the valuable evidence collected by Dr. Bulstrode and contained in the appendix to that report have drawn public attention to the very serious danger to public health which arises from the condition of certain of the oyster ponds and receptacles used for the storage of oysters in preparation for the market. The facts recorded in these reports as to the cases of the oyster ponds at Southend, Cleethorpes, Medina River, Penryn River, Brightlingsea Creek, Southwick, and Colne River, and in the cases of certain storage pits and other receptacles at Southend Pier, Blackwater River, Wivenhoe, Grimsby Fish Dock, Poole, Warsash, Bosham and Emsworth, show that in all these instances the oyster ponds or receptacles are subject to sewage contamination of the grossest and most dangerous description.

The case with respect to sewage-contaminated oyster beds and storage ponds is summarised by Dr. Bulstrode in these words:—

> "It must have been apparent from these descriptions and maps that at certain places along our coasts no care whatever has been exercised in the selection of localities for layings serving as fattening beds and for storage ponds, in order to ensure that oysters in these places should be reasonably free from risk of sewage pollution; and also it will be clear that considerations of accessibility and convenience have, in many instances at least, determined the selection of storage ponds, fattening beds and layings. A general view of the conditions will have served to demonstrate that many of the larger and more important oyster companies possess 'layings,' fattening beds and storage ponds, in the main free from the risks of dangerous sewage pollution; and that, moreover, where security in this sense does not obtain, it may—in not a few instances at least—be easily brought about by the simple expedient of altering the position of the fattening beds or storage pits. But, on the other hand, it will have been obvious to the reader that there are cases where the risk of sewage pollution to oysters is so great and so undeniable, that nothing short of complete diversion of the sewers or drains, or withdrawal of existing fattening beds or ponds from use, can be regarded as satisfactory in the public interest. It would indeed appear that, in several places along our coasts, the conditions are at

least equally bad, if not worse than those which are reported to have brought about the very remarkable outbreak of enteric fever at Wesleyan College, Connecticut, U.S.A."

The circumstances attending the trade in oysters and other shell fish in Brighton are such as to render the accurate tracing of the connection between the consumption of specifically contaminated shell fish and attacks of enteric fever easier than those usually existing in great towns.

The following is the chain of evidence which has enabled the medical officer of health to establish the connection between cases of enteric fever and the consumption of oysters and other shell fish:—

(a) Most of the oysters and mussels consumed in Brighton are derived from a particular source, concerning which it is only necessary to quote Dr. Bulstrode's remark (Report, p. 73): "Sufficient has come to light for the purpose of demonstrating that the Southwick oyster ponds are in a most improper and unsafe position."

(b) Enteric fever is endemic in the population whose drains and cesspools discharge near the oyster ponds and mussel beds in question.

(c) Sewage-derived organisms were found in the mud of the oyster ponds, and in the interior of oysters obtained from them, by Dr. Klein, F.R.S., and by Professor Boyce, of University College, Liverpool.

(d) In a large proportion of the cases the one person taking oysters or mussels from the above source within three weeks preceding the date of onset of illness is the one person subsequently taken ill with enteric fever.

(e) When other persons in the same house had eaten shell-fish they had diarrhœa or other evidence of illness, although this did not develope into typical enteric fever.

The following tabular statement shows that 30·7 per cent. of the total cases of enteric fever originating in Brighton during 1897 were definitely traceable to the eating of sewage-contaminated oysters or mussels, as compared with 31·8 per cent. in 1896, with 33·9 per cent. in 1895, and with 38·2 per cent. in 1894.

Table XLVI.

Year.	Total cases of local origin.	No. of cases in which it was stated that oysters or other shell fish had not been eaten.	No. of cases in which it was doubtful whether shell fish had been eaten.	No. of cases in which origin was directly traceable to oysters.	No. of cases in which origin was directly traceable to other shell fish.	Total of foregoing cases traceable to oysters and other shell fish.	Percentage of last-mentioned cases to total local typhoid cases.
1893 (from Midsummer) ..	31	19	6	6*	—	6	—
1894	55	33	1	16	5	21	38·2
1895	56	37	—	7†	12	19	33·9
1896	94	61	2	22‡	8	30	31·8
1897	88	47	11	11	16	27	30·7

* No secondary cases.
† Including one secondary case.
‡ Including two secondary cases.

Average percentage of cases of local origin in the four years, 1894-97, traceable to shell fish = 33·1 per cent.

Summary of Local Proceedings.

The spread of enteric fever by means of sewage-contaminated shell fish has been a cause of anxiety to the Brighton sanitary authority since the 29th March, 1894, when the sanitary committee had before them the particulars of eight cases of enteric fever which had occurred during the preceding quarter, and which were attributable to the consumption of oysters derived from oyster layings grossly contaminated by sewage. These particular beds will be described as X. in the present memorandum.

On April 19th, 1894, the sanitary committee had before them particulars of further cases of enteric fever arising from the same cause. At the same time samples of mud from the market ponds in question were submitted to bacteriological examination by Dr. Boyce, now Professor of Pathology, University College, Liverpool, who stated that the results pointed "unmistakeably to the presence in the imme-

diate vicinity of the oyster beds of sewage matter contaminated with human excreta."

On 20th April, 1894, the medical officer of health interviewed Mr. Power, the assistant medical officer of the Local Government Board (in the absence of Dr. Thorne), and urged the importance of the Local Government Board bringing pressure to bear upon the responsible local authorities to execute an efficient combined system of main sewerage. Such a scheme is still in the future, though an inspector of the Local Government Board has (December, 1897) held an inquiry into a proposed combined scheme affecting two out of four of the local authorities responsible for the pollution of the oyster and mussel layings at X.

The Brighton sanitary authority, during 1894, wrote to the port sanitary authority of Shoreham, and as the result of their letter the owners of the market ponds at X. were served with a notice from the port sanitary authority requiring them to close the oyster ponds. On August 18th, 1894, the medical officer of health reported that these ponds were again in use, and reported three additional cases of enteric fever traceable to oysters derived from them.

On October 11th, 1894, the medical officer of health found that the two small sewers adjoining the market ponds had been lengthened, so as to discharge 50 ft. and 78 ft., respectively, from the nearest ponds.

On December 7th, 1894, a deputation from the Brighton Town Council, consisting of the Mayor (Mr. Alderman Botting, J.P.), the chairman of the sanitary committee (the late Councillor Loader), Sir Joseph Ewart, J.P., Councillor McClean, town clerk, and the medical officer of health, waited upon the parliamentary secretary of the Local Government Board (Sir Walter Foster), who was accompanied by Sir Hugh Owen and Dr. Thorne Thorne. At this interview Sir W. Foster stated that "he regarded the site where the oyster ponds were now placed as an open sewer, and absolutely unfit for its present use." He added that "there was no doubt that the question was one of general importance, and that some general regulations for the control of the trade in shell fish were necessary."

The medical officer of health of Brighton continued to report, during the next two years, cases of enteric fever caused by sewage-contaminated shell fish as they arose. In his annual reports he made the statement that 38·2 per cent. (1894), 33·9 per cent. (1895), 31·8 per cent. (1896), and 30·7 per cent. (1897), of the total cases of enteric fever originating in Brighton were caused by sewage-contaminated shell fish. The Brighton sanitary authority, being impressed with the importance of obtaining powers to enable them to cope with a cause of disease which was responsible for one-third of their total indigenous enteric fever, attempted, in the session of 1896, to obtain parliamentary

powers authorising them to prohibit the sale, within the borough, of shell fish known or suspected to be the cause of infectious disease, similar to those which the Local Government Board are now asked in the memorial to confer upon local authorities generally. This clause was, however, rejected by the Police and Sanitary Committee of the House of Commons, largely, it is believed, because of the statement of the Local Government Board that their investigation on the subject was not complete, and because of the statement of the Board of Trade that powers of the nature asked for, if granted, should be general and not local.

The present law does not enable local authorities to prevent the sale, within their district, of shell fish from a source known to be grossly contaminated with sewage; and although cases of enteric fever may have been previously traced to the consumption of shell fish from the same source, the powers with respect to the seizure of unwholesome food (Public Health Act, 1875, s. 116) do not meet this case. It is impossible to say in a particular instance, without a bacteriological examination requiring from seven to ten days, whether a given lot of oysters exposed for sale contain typhoid bacilli. The recent failure to find typhoid bacilli in the Maidstone water, at a time when it was spreading enteric fever, shows that negative results cannot be trusted. The machinery of sect. 116 of the Public Health Act is quite inoperative when applied to the requirements of this case.

Town Hall, Brighton,
February 4th, 1898.

Dr. Newsholme further pursued the question in a paper read before the Sanitary Institute (Vol. XVII., Part III.) on "The Spread of Enteric Fever by means of Sewage-contaminated Shell Fish," from which the following is abstracted:—

Experiments on viability of typhoid bacilli in oysters. (*A.*)—Professor Rubert Boyce, M.B., Professor of Pathology, and Professor W. A. Herdman, D.Sc., F.R.S., Professor of Zoology in University College, Liverpool, described at the Ipswich meeting (1895) of the British Association experiments made by them.

They summarise their experiments bearing on the present question as follows:—

IV. *The toleration of sewage, &c.*—It was found that oysters could, up to a certain point, render clear sewage-contaminated water, and that they could live for a prolonged period in water rendered opaque by the addition of fæcal matter; and that the fæcal matter obtained from cases of typhoid was more inimical than that obtained from healthy subjects.

V. *The infection of the oyster by the micro-organisms.*—The results of the bacteriological examination of the water of the pallial cavity of the oyster, and of the contents of the rectum, showed that in the cases of those laid down in the open water of the bay the colonies present were especially small in number, whilst in those laid down in proximity to the drain-pipe the number was enormous (*e.g.*, 17,000 against 10 in the former case). It was found that more organisms were present in the pallial cavity than in the rectum. In the case of the oysters grown in water infected with the *bacillus typhosus*, it was found that there was no apparent increase of the organisms, but that *they could be identified in cultures taken from the water of the pallial cavity and rectum fourteen days after inspection.*

It is found that the typhoid bacillus will not flourish in clean salt water, and our experiments seem to show, so far, that it decreases in numbers in its passage along the alimentary canal of the oyster.

(*B.*)—Dr. Charles J. Foote, of the Yale Medical School, U.S.A., found that the typhoid bacilli were alive forty-eight hours after being placed in the interior of the shell of a living oyster, and the same time after inoculation into the oyster. Experiment was not continued beyond this time.

Experiments on viability of typhoid bacilli in sea water.—Experiments of Giaxa show that the typhoid bacilli can maintain their vitality in sea water, sterilized or not, for many days. (Quoted in the "British Medical Journal," p. 392, February 16th, 1895.)

Experiments of Freytag show that the typhoid bacillus will live six months in a concentrated solution of salt.

Foster has also shown that the typhoid bacillus will resist the action of a saturated solution of salt for weeks, and even for months. (Quoted by Dr. C. J. Foote, Report of Connecticut State Board of Health, Report for 1894, page 265.)

Viability of typhoid bacilli in fresh water.—Cassedebat, examining the drinking water of Marseilles (a very hot-bed of water-borne typhoid fever), could not find the characteristic bacilli in one out of 250 cultivations made of seventy specimens of water, though he found others closely resembling them.

The reason was not, as pointed out by Cassedebat, because the typhoid bacillus will not live in water, as in distilled water to which a cultivation of typhoid bacilli was purposely added he could distinguish their presence *at the end of forty-four days*, and when they were added to distilled water along with half-a-dozen other forms, they were still living and active at the end of seventeen days. ("Annal de l'Institut Pasteur," October 25th, 1890.)

Klein ("Twenty-fourth Annual Report of the Local Government Board," Supplement of the Medical Officer, page 417) found in some

experiments that "by adding in the first instance large numbers of typhoid bacilli—always, be it noted, along with a trace of nutritive material—to samples of London water, sterilized by filtration before inoculation, living bacilli were recoverable therefrom, in two out of the three samples, even after the lapse of eight weeks."

Experiments on viability of typhoid bacilli in sewage.—Messrs. Lawes and Andrewes, in their report to the London County Council, showed that typhoid bacilli inoculated into sterilized sewage died within a few days, when the sewage was maintained at 37° C. At 20° C., the ordinary temperature of the air, the duration of their life was longer, but probably not over a fortnight.*

It is necessary to note that—(*a*) these were laboratory experiments, not made under natural conditions.

(*b*) Only small quantities of the sewage were tested, and the negative results are therefore not conclusive.

(*c*) Further, it has been shown above that the typhoid bacilli will live for months in sea water, and that they will live in oysters inoculated with them at least fourteen days. (Boyce and Herdman.)

Later experiments made by Klein on similar lines ("Twenty-fourth Supplement of the Medical Officer to the Local Government Board," page 407) showed that colonies of typhoid bacilli remained in sterile sewage at the end of three weeks from the time of its artificial inoculation. Furthermore, in sterile sewage to which nitrates had been added, the typhoid bacilli continued to exist in enormous numbers at the end of eight weeks.

More recently, in spite of the warnings thus conveyed, many further cases of typhoid have occurred from eating contaminated oysters, with the loss of valuable lives and a serious injury to the oyster industry.

In his Annual Report, published 30th March, 1903, Dr. Newsholme again drew attention to the danger from contaminated shellfish, and gave some further instances of cases of enteric fever arising therefrom. On 19th February, 1903, the Brighton Town Council passed a draft bye-law pro-

* These experiments, while perfectly trustworthy on the *minimum* side, almost certainly do not indicate the maximum duration of life of the typhoid bacillus in the soil, as it is impossible to say that the negative results obtained at the end of a given time prove the actual absence of living typhoid bacilli.

hibiting the sale, or exposure for sale, in the Brighton Fish Market, of oysters or other shellfish known to have come from a sewage-contaminated source, and forwarded it to the Local Government Board for approval.

In view of these facts, it cannot be doubted that the system of discharging crude sewage into streams flowing directly over or near oyster, cockle, or mussel beds should be absolutely prohibited, which prohibition should also apply to the discharge of crude sewage into the sea along the coast within a considerable distance of any seaside resort. Two or three miles away is entirely insufficient, as the tidal flow will soon travel this distance, with, to say the least, a by no means pleasant result to those who look for pure-water bathing.

One of the modern methods which have been favourably looked upon is to allow the sewage to undergo putrefactive decomposition in a tank before its discharge into the sea, without any further purification on aërobic beds. This is not sufficient. The idea is to save the expense of pumping and the cost of constructing the beds. Nothing can be more fallacious than this false economy. It will soon become recognised that certain seaside resorts do not employ proper and effective methods for purifying their sewage, and the resulting loss to the town by the abstention of visitors will far more than make up for the slight saving on the rates. When methods for purifying sewage were both ineffective in operation and expensive in working, and little or nothing was known of the serious danger caused to health by bad effluents, then there was some excuse; but at the present time there is absolutely none, and it is to be hoped that all seaside towns will avail themselves of the advance of knowledge both in regard to improved methods of purification and the danger of the old system, and cease from corrupting their bathing resorts and food supplies.

CHAPTER XIV.

THE FILTRATION OF POTABLE WATER.

THE first water purifier for which protection was obtained in this country is that of William Walcott, who in 1675 obtained a patent for the "art of makeing water corrupted fit for use, and sea water fresh, clear, and wholesome in very large quantities, by such wayes and means as are very cheap and easy, and which may be done and practised with great speed and expedicion." Unfortunately these "wayes and means" are not given in the specification; but doubtless it was a method of distillation.

It is not until the year 1790 that we find mention of any contrivance which can claim to be regarded as a filter, when Johanna Hempel patented a method of making porous vessels which were to be used as filters, the substances used being clay and sand. In the following year upward filtration was patented, the materials employed being "sand, sandy gravel, and broken or pulverised glass." Wood charcoal was introduced in 1802. Ten years later, in 1812, we have the first rudimentary idea of oxidation, when Messrs. Dickinson and Maudsley proposed to oxidise the organic matter by simply forcing a stream or streams of air through the foul or tainted water by means of bellows or pumps. This may be looked upon as the forerunner of the system adopted by Lowcock for the filtration of sewage effluent, and Waring for that of crude sewage.

In 1818, John Bennett proposed to use animal charcoal, in combination with sand, gravel, and "a very fine ground charcoal of Prussian blue, made by potash."

The extraordinary number of organic matters which were used by the earlier filter makers is very curious. Wood, leather, paper, sponge, hair-cloth, horse-hair, wool, skins of animals, cotton, felt, linen, &c., in addition to the usual sand, gravel, shells, &c. The want of elementary knowledge is here curiously illustrated by the early manufacturers overlooking the fact that organic materials decompose and eventually render the water worse after filtration. Again, most of them proposed to clean the filtering materials by forcing the water the reverse way instead of entirely removing them for a good washing, &c. This method is even at the present time recommended as effective. Bad, indeed, must be the water before filtration when such a system can be adopted with advantage. Such filters are little better than sieves. It is well known that where a new supply of filtering material is not obtainable the most efficacious method is to remove the old charcoal, &c., well wash it, and then heat it in a closed vessel to a red heat, when it will be thoroughly renovated.

The now well-known "block" filters were first introduced by Samuel Bagshaw in 1834, who constructed his block by mixing charcoal, stone, and clay, with water into a paste, which was then moulded to shape, dried, and heated in an oven or retort.

In 1838, Matthew Heath proposed to clarify the water by "precipitating the heterogeneous insoluble matter by means of a solution of muriate of zinc." This startling process, however, was disclaimed later on.

The proposition to use canvas bags in order to obtain as large a filtering surface as possible seems to have been a favourite one, and as a strainer the system is largely adopted, but it cannot strictly be called filtration in the ordinary sense.

In 1852, the necessity for radical measures seems to have been urgent, as in that year one gentleman proposed certain improvements in the method of treating water, to wit:—The water was to be first chemically treated, then distilled, again chemically treated, and finally filtered, no particular filter being mentioned. A few years later another inventor was determined that he would be on the safe side, so he constructed a filter as follows:—First, a perforated stage on which was laid a layer of pebbles; then fragments of granite; a piece of hair-cloth; a bed of ground glass; a second piece of hair-cloth, upon which was laid a "terro-metallic" bed, which contained flint, steel filings, oxalate of ammonium, peroxide of manganese, animal charcoal, and boxwood charcoal; above this was laid another covering of hair-cloth, and then a perforated stage. Below this filtering bed, a powder, containing oxalate of ammonium, peroxide of manganese, and charcoal, was placed to soften hard waters.

Amusing as it may be to read such descriptions as these in the light of our present knowledge, one cannot forget that those early pioneers served the useful purpose of indicating a necessity, and at the same time by their stumblings as surely indicating the dangers and difficulties of the road for the guidance of those who follow them.

The first scientific and practical method of treating hard waters especially is that of Dr. Thomas Clark, who in 1841 patented his famous method of softening water by adding lime water to the hard water in sufficient quantity to absorb the carbonic acid which holds the carbonate of lime in solution. As soon as the excess of acid is thus removed, the carbonate of lime in the water, and the lime put in and now combined with the carbonic acid, settles to the bottom of the containing vessels, and in doing so carries with it practically the whole of the impurities in the water.

The process is one of the most simple and beautiful methods

of treating water which has been brought before the public; and, although it has been adopted at certain waterworks, as well as in very numerous factories, the marvel is that the inhabitants of the great metropolis are deprived of its advantages by the failure of the water companies to carry out the process, which is easy, simple, safe, and inexpensive. When it is considered that eightpennyworth of lime will soften as much water as forty-seven pounds' worth of soap, in addition to the advantage to be derived by preventing the corrosion and stopping up of hot-water pipes, boilers, &c., it becomes astonishing that the public should have been so patient.

It is often claimed for filters that they will remove living organisms as well as the ordinary impurities. Up to a certain extent this is true, but by no means entirely so, more especially in relation to the bacteria. When we consider the conditions of the case, we shall understand better how a filter will, under suitable circumstances, allow organisms of various sizes to pass through, and in fact to live and multiply in it, with the result that after a time such a filter may become a perfect aquarium in itself.

All filters are made of a porous substance, whether compressed into blocks or not, the medium being in small granular pieces having interstices between them. These act very well when they deal with inert matter, but when the particle to be arrested is alive and swimming freely the case is altered. It is probably drawn into the filter by the rush of water, or swims in and finds itself wandering about in what are comparatively large caverns. It swims on and on, turning and twisting about until it emerges at the outlet of the filter, and is at large in the filtered water. This is more specially so in the case of those filters constructed of coarse granular substances, and it is obvious that the finer the material the smaller will be the organism that can pass. But this is supposing the case of a free swimming organism.

Let us consider what will happen with a bacterium growing in chains, &c. The pores of the filter may be too small even for this minute body to pass freely. Very well, the bacterium will quietly settle against the side of the filter or on its exposed part, wherever that may be, and begin to grow. As it grows by thrusting out shoot after shoot, some of these will penetrate the infinitely minute pores of the filter, like the roots of ivy on a brick wall; and in time it will actually penetrate the filter. This consideration points out the fallacy of the supposition that such a filter can be completely cleaned by running the water backward.

The action of a filter in removing matters in solution in a water may be considered as twofold in character. First, the action of gravity brings about the adherence of the molecules to the sides of the solid matter of which the filter is composed, just as it causes a chip of wood floating in water to adhere to the sides of a larger fragment or of a boat. Second, a process of chemical change brought about either by the life processes of bacteria, or a process of "catalysis" resulting in slow oxidation under favourable conditions. The law of gravity teaches us that both the larger and smaller particles are attracted, and actually move one to the other; but as the movement of the greater mass is slower in proportion to its bulk, so the movement of the mass of a filter towards a molecule of matter dissolved in the water will be only practically a mathematical expression, whilst the molecule will move with appreciable rapidity. Let this be tried by placing two pieces of wood in still water, the larger piece being, say, three or four inches square, and the smaller only a splinter. Place them half an inch apart, and watch. The mathematician will tell us that both will move towards each other; but, to our vision, the movement of the larger will be imperceptible, whilst gradually the smaller will move towards the larger, increasing its pace until it finally rushes

towards it, and clings with no little force. This action is doubtless precisely that which takes place in a filter. If the rapidity of the stream of water passing through the pores of the filter is not too great, the minute particles of matter in the water will adhere by the action of gravity to the walls of the cells in the filter, and will be retained there until they are destroyed, either by the life-action of the bacteria which will abound in the filter, or by a process of slow oxidation in certain cases. If the substances thus removed from the water are mineral in character, and therefore not capable of being destroyed by either of these agencies, they will gradually accumulate until the cells are filled with them, and the filter will be in the condition known as "choked" or "sludged up."

This description of the action, which it is only reasonable to presume takes place in the case of the solid matters suspended in a water, may be used as a guide to that which occurs when matters dissolved in the water are removed therefrom by the process of filtration.

The following experiments which I carried out in 1878 will help to illustrate the point. A solution of acetate of lead was prepared, of such strength that it contained metallic lead in the proportion of one grain per gallon. This was slowly filtered through a 5½-inch carbon-block filter, when the filtrate was found to contain no lead, the whole having been retained in the pores of the filter. A second solution of similar strength to the above was next filtered rather more rapidly, when the first portions of the filtrate contained two-tenths of a grain of lead per gallon, and the last portions three-tenths of a grain per gallon. A third gallon of lead solution of similar strength was then passed through the filter, when the first portions of filtrate were found to contain two-tenths of a grain of lead per gallon, and the last portions as much as six-tenths of a grain per gallon. A fourth

gallon of lead solution was then passed through the filter, when the filtrate was found to contain five-tenths of a grain per gallon. Thus the filter gradually lost its power to either (a) take up lead from solution, or (b) to retain that which it had previously absorbed. If we consider the molecules of lead dissolved in the water as synonymous with the minute splinter of wood above referred to, we can follow the action. At first the cell-walls of the filter are free from lead, and the molecules of that substance adhere to them by *the action of gravity* or "*mass-action.*"

After a certain quantity of lead had been taken up, and the rate of passage of the water was slightly increased, the filter failed to retain the whole of the lead, which failure may be compared to that of a large piece of wood failing to retain small chips when the current of water is strong enough to wash them away from its side. Doubtless, as it appears to me, some of the molecules of lead became attached to the cell-walls, whilst others more loosely adhering were washed free again by the force of the current, whilst others again passed through certain cellular passages at such a pace that their movement was faster than the gravitational force moved them to the cell-walls, and hence they passed through the filter. Similar results were obtained with solutions of quinine and morphia. At first, the filter removed the whole or nearly the whole of the alkaloid from solution, and then only a portion, whilst subsequent rapid filtration of pure water removed portions of the alkaloids from the cells of the filter.

These considerations explain why a finely-divided material makes a better filter than a coarser material, because the smaller the cells of the filter the better chance is there for the contact action induced by gravity to have full play, and why a slower rate of filtration always ensures a better filtrate, as too rapid passage of the water washes away the "chips"

from the "block." It will further be easily understood why the nature of the substance of which the filter is composed is of less importance than the size of the cells of which the filter is made up. There has been much misconception upon this point.

The Filtration of Public Water Supplies.—The following table indicates the character of the filter beds employed by the London water companies for filtering the water taken from the rivers Thames and Lea.

Table XLVII.

Maximum Depth of Sand and other Materials used in the Filters of the London Water Companies. Extracted from the Report of the Water Examiner, General A. de C. Scott, for the Month of November, 1896.

Chelsea.

Sand, &c.	ft.	in.
Thames sand	4	6
Shells, &c.	0	3
Gravel	3	3
Total	8	0

East London.

Sand, &c.	ft.	in.
Sand	2	0
Hoggin	0	6
Coarse gravel	1	0
Total	3	6

Lambeth.

Thames sand	3	0
Shells, &c.	1	0
Coarse gravel	3	0
Total	7	0

TABLE XLVII.—*continued.*

Grand Junction.

Old pattern—	ft.	in.
Harwich sand	2	6
Hoggin	0	6
Fine gravel	0	9
Coarse gravel	0	9
Boulders	1	0
Total	5	6
New pattern—		
Sand	2	0
Gravel	0	6
Drains	0	3
Total	2	9

New River.

Sand	2	3
Gravel	3	4
Increasing in coarseness towards bottom.		
Total	5	7

Southwark and Vauxhall.

Harwich sand	3	0
Hoggin	1	0
Fine gravel	0	9
Coarse gravel	0	9
Total	5	6

West Middlesex.

Harwich sand	1	9
Barnes sand	1	0
Gravel	1	0
Screened to different sizes and arranged in layers.		
	3	9

Table XLVIII.

Subsiding and Storage Reservoirs for Unfiltered Water; Available Capacity in Gallons per Million Gallons Supplied.

Chelsea	12,200,000
East London	21,600,000
Grand Junction	3,500,000
Lambeth	6,180,000
New River	5,120,000
Southwark and Vauxhall	4,300,000
West Middlesex	5,960,000

Table XLIX.

Filtering Area in Acres, per Million Gallons of the Average Daily Supply.

Chelsea	0·58
East London	0·64
Grand Junction	1·13
Lambeth	0·50
New River	0·43
Southwark and Vauxhall	0·61
West Middlesex	0·72

Table L.

Average Rate of Filtration per Square Foot per Hour, Gallons.

Chelsea	1·75
East London	1·33
Grand Junction	1·63
Lambeth	1·80
New River	2·25
Southwark and Vauxhall	1·50
West Middlesex	1·25

From the above tables it will be seen that there is a considerable divergence in the system adopted, the total depth of filtering material varying from 8 ft. in the case of the Chelsea Company to 2 ft. 9 in. in that of the Grand Junction Company. In conjunction with this factor, the available capacity, in gallons per million supplied, of the subsiding and storage reservoirs for unfiltered water must be considered, as natural

sedimentation plays no inconsiderable part in relieving the work to be done by a filter. The filtering area per million gallons, and the average rate of filtration, are also matters of the first moment. In considering Tables XLIX. and L., it must be pointed out that the New River Company avails itself largely of well water; and the river Lea, above its intake, is less fouled by floods than it is lower down the valley. The Southwark and Vauxhall and the Grand Junction Companies have the means, during floods, of pumping from the gravel beds adjoining the Thames, and this is practically equivalent to an addition to their storage resources. Any comparison between the methods of the respective companies is thus rendered extremely difficult, and for our present purpose unnecessary, it being desired to point out, from a general standpoint, the character of the operations adopted, under most skilful advice and direction, for freeing the water derived from a more or less polluted source from impurities, whether held in solution or in suspension.

The following represents the composition, according to Professor Mason, of some filter beds on the Continent and in America:—

TABLE LI.

	Berlin.	Warsaw.	Zürich.	Hague.	Hudson, N. Y.	Poughkeepsie, N. Y.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
Fine sand	1 10	2 0	2 8	1 0	0 6	2 0
Coarse sand	0 2	—	0 6	0 10	1 6	—
Fine gravel	0 6	0 2	0 4	—	0 6	—
Medium gravel....	0 5	—	—	—	0 6	1 6
Coarse gravel	0 3	0 3	0 6	0 10 (sea shells)	0 6	—
Small stones.....	0 4	1 0	—	—	0 6	0 6
Large stones.....	1 0	0 11	—	0 6	2 0	2 0
Total	4 6	4 4	4 0	3 2	6 0	6 0

In order to remove the grosser particles held in suspension in the water, the system of storing it in large reservoirs affords a most valuable and in many cases essential auxiliary to the filtration plant.

The process of sedimentation, as it is termed, in such reservoirs not only assists in producing a clear and bright water by the settlement of the suspended matters, but under favourable circumstances conduces to a diminution of the impurities actually dissolved in the water. Dr. Percy Frankland has shown that, in a certain case, the number of bacteria present in a water before passing into a storage reservoir was 1,437 per cubic centimetre; after storage, these were reduced to 318; and after storage in a second reservoir, to 177 per cubic centimetre. This fact is only what might be expected from the settlement of the suspended matters, as in the course of my own experience the number of bacteria almost always followed the ratio of suspended particles, as will be seen from the following table:—

TABLE LII.

Description of Water.	Suspended particles. Grains per gallon.	Bacteria, per c.c.
Kent Company's supply, 1895	0·0011	90
New River ,, ,, ,,	0·0011	130
West Middlesex ,, ,,	0·0010	130
Chelsea ,, ,,	0·0027	139
Grand Junction ,, ,,	0·0023	170
East London ,, ,,	0·0023	277
Lambeth ,, ,,	0·0033	294
Southwark and Vauxhall ,,	0·0056	352
River Thames at Sunbury	0·5360	16,061
Sewage	30·0000	2,000,000

The results in the case of the companies' waters and that of the Thames at Sunbury are the averages of daily examinations during twelve months, while that of the sewage is the mean of very numerous determinations on the London sewage.

The following tabular statement by Dr. Percy Frankland shows the character of the sands used in various places for water filtration :—

TABLE LIII.

Analyses of Sands used in Water Filtration.

Source.	Effective size; 10 per cent. finer than Millimetres.	Uniformity coefficient.	Remarks.
London—			
East London Co.	0·44	1·8	[washed New sand never used or
,, ,,	0·39	2·1	Dirty sand, very old
,, ,,	0·37	2·0	Same, washed by hand
Grand Junction	0·26	1·9	Sand from rough filter
,, ,,	0·40	3·5	Old sand in final filter
,, ,,	0·41	3·7	Freshly washed old sand
Southwark and Vauxhall.	0·38	3·5	,, ,, ,,
,, ,,	0·30	1·8	,, ,, new ,,
Lambeth	0·36	2·3	,, ,, old ,,
,,	0·36	2·4	New unused sand, washed
,,	0·25	1·7	New extremely fine sand
Chelsea	0·36	2·4	Freshly washed old sand
Middlesbrough	0·42	1·6	Dirty sand, ordinary scraping
,,	0·43	1·6	Same, after washing
Birmingham	0·29	1·9	Dirty sand
,,	0·29	1·9	Sand below surface of filter
Reading	0·30	2·5	Dirty sand
,,	0·22	2·0	Same, after washing
Antwerp	0·38	1·6	Dirty sand
,,	0·39	1·6	Same, after washing
Hamburg	0·28	2·5	Dirty sand
,,	0·31	2·3	Same, after washing
,,	0·34	2·2	Dirty sand, another sample
,,	0·30	2·0	Same, after washing drums
,,	0·34	2·3	Same, after washing ejectors
Altona	0·32	2·0	Dirty sand, old filters
,,	0·37	2·0	Same, after washing
,,	0·33	2·8	Washed sand for new filters
Berlin—			
Stralau	0·33	1·9	Dirty sand pile
,,	0·35	1·7	Filter No. 6, 3in. below surface
,,	0·34	1·7	Filter No. 7, 3in. below surface
,,	0·35	1·7	Filter No. 10, 3in. below surface
Tegel	0·38	1·6	Dirty sand, old filters
,,	0·38	1·5	Same, after washing, old filters
,,	0·35	1·6	,, ,, new filters
Müggel	0·35	1·8	Sand from filters below surface
,,	0·33	2·0	Dirty sand, ordinary scraping
,,	0·34	2·0	Dirty sand, another sample

TABLE LIII.—*continued.*

Source.	Effective size; 10 per cent. finer than Millimetres.	Uniformity coefficient.	Remarks.
Charlottenburg	0·40	2·3	Dirty sand
Chemnitz	0·35	2·6	New sand not yet used
Magdeburg	0·39	2·0	Dirty sand
,,	0·40	2·0	Same, after washing
Breslau	0·39	1·8	Normal new sand
Budapest	0·20	2·0	New washed Danube sand
Zürich	0·28	3·2	Dirty sand
,,	0·30	3·1	Same, after washing
Hague	0·19	1·6	Dune sand used for filtration
Schiedam	0·18	1·6	Dune sand used for filtration; dirty
,,	0·31	1·5	River sand; dirty
Amsterdam	0·17	1·6	Dune sand
Rotterdam	0·34	1·5	River sand; new
Liverpool—			
Rivington	0·43	2·0	Sand from bottom of filter
,,	0·32	2·5	New sand unwashed and unscreened
,,	0·43	2·7	Washed sand which has been in use thirty to forty years
Oswestry	0·30	2·6	Dirty sand
,,	0·31	4·7	Same, after washing

The exceptionally fine sand employed at some of the Dutch waterworks is particularly noteworthy.

As indicating the methods recommended for the guidance of water companies in Germany the following regulations, issued by the German Government, and which, it is understood, have been drawn up under the supervision of Dr. Koch, will be of interest and value:—

(1.) In judging the quality of a filtered surface water, the following points should be specially observed:—(*a*) The operation of a filter is to be regarded as satisfactory when the filtrate contains the smallest possible number of bacteria, not exceeding the number which practical experience has shown to be attainable with good filtration at the works in question, in those cases where there are no previous records showing

the possibilities of the works and the influence of the local conditions, especially the character of the raw water: and until such information is obtained it is to be taken as the rule that a satisfactory filtration shall never yield an effluent with more than about 100 bacteria per cubic centimetre. (*b*) The filtrate must be as clear as possible, and in regard to colour, taste, temperature and chemical composition, must be no worse than the raw water.

(2.) To allow of a complete and constant control of the bacterial efficiency of filtration the filtrate from each single filter must be examined daily. Any sudden increase in the number of bacteria should cause a suspicion of some unusual disturbance in the filter, and should make the superintendent more attentive to the possible causes of it.

(3.) Filters must be so constructed that samples of the effluent from any one of them can be taken at any desired time for bacteriological examination.

(4.) In order to secure uniformity of method, the following is recommended as the standard method for bacterial examination:—The nutrient medium consists of 10 per cent. meat extract gelatin with peptone, 10 cubic centimetres of which is used for each experiment. Two samples of the water under examination are to be taken, one of 1 cubic centimetre and one of $\frac{1}{2}$ cubic centimetre. The gelatin is melted at a temperature of 30 deg. Cent. to 35 deg. Cent., and mixed with the water as thoroughly as possible in the test-tube by tipping backwards and forwards, and is then poured upon a sterile glass plate. The plates are put under a bell-jar which stands upon a piece of blotting paper saturated with water, and in a room in which the temperature is about 20 deg. Cent. The resulting colonies are counted after forty-eight hours, and with the aid of a lens. If the temperature of the room in which the plates are kept is lower than the above, the development of the colonies is slower, and the counting

must be correspondingly postponed. If the number of colonies in 1 cubic centimetre of the water is greater than about 100, the counting must be done with the help of Wolffhügel's apparatus.

(5.) The person entrusted with the carrying out of the bacterial examinations must present a certificate that he possesses the necessary qualifications, and wherever possible he shall be a regular employé of the waterworks.

(6.) When the effluent from a filter does not correspond with the hygienic requirements it must not be used, unless the cause of the unsatisfactory working has already been removed during the period covered by the bacterial examinations. In case a filter, for more than a very short time, yields a poor effluent, it is not to be used until the cause of the trouble is found and corrected. It is, however, recognised from past experience that sometimes unavoidable conditions (high water, &c.) render it impossible, from an engineering standpoint, to secure an effluent of the standard quality. In such cases it will be necessary to use a poorer quality of water; but, at the same time, if such conditions arise as outbreaks of epidemics, suitable notice should be given of the condition of the water.

(7.) Every single filter must be so built, that when an inferior effluent results, which does not conform to the standard, it can be disconnected from the pure-water pipes and the filtrate allowed to run to waste. This wasting should as a rule take place, so far as the arrangement of the works will permit,—(1) immediately after scraping a filter; and (2) after replacing the sand to the original depth. The superintendent must himself judge, from previous experience acquired by the continual bacterial examinations, whether it is necessary to waste the water after these operations, and if so, how long a time will probably elapse before the water reaches the standard purity.

(8.) The best sand filtration requires a liberal area of filter surface, allowing plenty of reserve, to secure, under all local conditions, a moderate rate of filtration adapted to the character of the raw water.

(9.) Every single filter shall be independently regulated, and the rate of filtration, loss of head, and character of the effluent shall be known. Also each filter shall, by itself, be capable of being completely emptied, and, after scraping, of having filtered water introduced from below until the sand is filled to the surface.

(10.) The velocity of filtration in each single filter shall be capable of being arranged to give the most favourable results, and shall be as regular as possible, quite free from sudden changes or interruptions. On this account reservoirs must be provided large enough to balance the hourly fluctuation in the consumption of water.

(11.) The filters shall be so arranged that their working shall not be influenced by the fluctuating level of the water in the filtered-water reservoir or pump-well.

(12.) The loss of head shall not be allowed to become so great as to cause a breaking through of the upper layer on the surface of the filter. The limit to which the loss of head can be allowed to go without damage is to be determined for each works by bacterial examinations.

(13.) Filters shall be constructed throughout in such a way as to insure the equal action of every part of their area.

(14.) The sides and bottoms of filters must be made water-tight, and special pains must be taken to avoid the danger of passages or loose places through which the unfiltered water on the filter might find its way to the filtered-water channels. To this end special pains should be taken to make and keep the ventilators for the filtered-water channels absolutely tight.

(15.) The thickness of the sand-layer shall be so great that under no circumstances shall it be reduced by scraping to less than 30 centimetres (= 12 in.), and it is desirable, so far as local conditions allow, to increase this minimum limit. Special attention must be given to the upper layer of sand, which must be arranged and continually kept in the condition most favourable for filtration. For this reason it is desirable that, after a filter has been reduced in thickness by scraping, and is about to be refilled, the sand below the surface, as far as it is discoloured, should be removed before bringing on the new sand.

(16.) Every city in the German Empire using sand-filtered water is required to make a quarterly report of its working results, especially of the bacterial character of the water before and after filtration, to the Imperial Board of Health.

(17.) The question as to the establishment of a permanent inspection of public waterworks, and if so, under what conditions, will be best decided after such quarterly reports have been furnished over some period of time.

It appears, from the report of the Water Examiner for the metropolis, General A. de C. Scott, R.E., for the month of November, 1896, that in August, 1892, the Local Government Board, in view of the prevalence of cholera on the Continent, its possible introduction into this country, and the importance of the efficient filtration of the Metropolitan water supply, requested the particular attention of the directors of the water companies to the following points, viz. :—

(1.) That every effort should be made to maintain the layer of sand in each filter at the greatest practicable thickness.

(2.) That the rate of filtration should be as slow as possible, consistently with the supply of the required quantity of water.

(3.) That the sand removed from the surface of the filters, with the deposit, should, if it was to be replaced in the filter, be completely freed from all taint of organic matter.

It is an opinion generally held by bacteriologists who have studied water filtration from their own point of view, that the longer a filter has been in use the more bacterially effective it becomes, and that the cleansing of the surface should be performed as seldom as possible. This opinion is grounded on the results of experiments.

It is necessary to guard against the conclusion which might follow, that the return to the filter of dirty and imperfectly washed sand is a course which is necessarily safe and even expedient.

The sand removed from the surface of the fields, together with the mud and impurities, mostly of vegetable, but to some extent of animal origin, is deposited in heaps, where it remains for some months, so that processes of decay and putrefaction are set up. The net bacterial result of these processes is undetermined, and may be totally different from that which obtains on the surface of the sand under water.

This consideration, independent of those which may be called sentimental, indicates the desirability of the thorough washing of the included sand before its replacement on the filters.

It appears from this report that instructions, drawn up by Professors Frankland and Dewar, with reference to the manner in which filtration should be carried out, prescribe, amongst other things, that after a filter has been re-charged with water an interval of rest should follow, during which sedimentation may take place, causing the formation of a skin or layer of slime or mud, which apparently constitutes the most effective portion of the filter from the point of view of bacterial interception.

In the course of a paper read before the Institution of Civil

Engineers on November 24th, 1896, Dr. Percy Frankland observed in reference to a former paper read by him in 1886, as follows :—

"The principles then enumerated were as follows :—

"(1.) To give the maximum period of storage for the unfiltered water.

"(2.) To filter at a minimum rate.

"(3.) To filter through a maximum depth of fine sand.

"(4.) To frequently renew the filtering materials.

"In reviewing the numerous investigations which have since been carried out on this subject, it will be shown that the only one of these principles which requires any modification, by the light of more recent research, is the last. Further researches appear to show that the power of arresting bacteria possessed by a filter-bed suffers no diminution with age, so that frequent scraping is not necessary for the maintenance of the efficiency of the individual bed. It is, however, quite possible that it may be of advantage for the efficiency of the filtration plant taken as a whole. Thus, by running a filter-bed over a long period of time without cleaning, its yield becomes diminished, and as a certain volume of water must be supplied daily, this may necessitate filtering through other beds at a disadvantageously high rate, and so obtaining a filtrate from the entire works inferior in bacterial quality to that which would result if scraping were practised more frequently and a more uniform rate of filtration employed with all the beds."

In the case of the filtration of sewage waters it has been definitely shown that the continuous passage of the water through a filter has the effect of rapidly choking the pores of the bed, and, in consequence of the absence of an ample supply of air, putrefaction will soon set in; but when the water is applied intermittently, the filter being thoroughly drained

and allowed a period of rest, the whole of the organic matter in the water undergoes a process similar in its ultimate effect to that produced by burning. The argument follows that if this is the case with one class of organic matter, why not equally so in the case of a water charged with practically similar organic matter, but considerably less in quantity? It is just at this point that further experiments are required. The Massachusetts experiments, although resulting in most valuable information, have not yet been sufficient to demonstrate the point in all its bearings. In the observations of the Massachusetts State Board of Health, 1890, Part II., page 601, it is stated that:—"It is evident that the impurities removed from the water during those two months (November and December, 1887) must have been in large part retained by the sand. There was no indication of any burning process by which the organic matter could be changed to mineral matter." This result, however, was changed, as on page 610 of the same volume it is observed:—"Without knowing all of the conditions that are essential to nitrification, we find in several of the tanks what appear to be striking parallels to the conditions that would exist if the organic material were burned by fire. There must first be an accumulation of combustible material. When started, the rapidity and completeness of combustion is greatest where most material has been accumulated. In filter No. 8 the greatest rapidity of burning was in May and June, 1888, after four months of accumulation, with no nitrification. This was followed by two months of slow burning, growing more feeble, until extinguished in September. Some accumulation of material occurred in the next three months, and the burning again started in December, and continued feebly through the cold months, and, becoming more active in April and May, burned with greatest intensity in June, though with less intensity and shorter duration than in the previous year, apparently for the reason that there was

less to burn, until—the stored material being nearly exhausted —it burned feebly but continuously the organic matter daily supplied through the following months."

It cannot be overlooked that even when the greatest possible care is exercised, there yet remains a danger from the accidental breakdown of the system of filtering water on a large scale, and as the strength of a chain is but that of its weakest link, it is useless to point to the satisfactory results obtainable when the system is working at its best.

In order to provide against such contingencies, when a water is drawn from a polluted source, there can be but few, if any, better systems than that of Dr. Clark's system of softening the water wherever possible. As will be seen in the next chapter, the effect of this system is to remove practically all but the last minute traces of impurity, and thus to constitute a second line of defence in case of the breakdown of the filters, or one of them, in addition to yielding a supply of water of far greater commercial value by reason of its better adaptability for use in steam boilers, hot-water systems, and the reduced consumption of the domestic soap, which item alone would effect an economy more than equal to the cost of the system.

CHAPTER XV.

SYSTEMATIC EXAMINATION OF POTABLE WATER.

The necessity for special investigation into the character of the microbes in water is brought out very clearly by the presence of epidemics in various parts of the country. Over and over again the same sequence of events has happened. Individuals and authorities have been warned that, if a certain condition of things continues, disease will infallibly follow, and in response one is often told that one is only an alarmist. The sad object lesson of the Maidstone epidemic is but Nature's answer to all those who persistently adhere to the old methods. When authorities recognize the fact that practical immunity can be secured by taking advantage of the knowledge obtainable by means of systematic analyses of the water daily, or at least weekly, we shall be in a far stronger position to defeat the foe which insidiously approaches in the form of disease of a most deadly character.

What would be thought of a military encampment in which sentinels were posted only when the enemy was in sight? And yet what is the difference between this state of things and that in which we allow ourselves to be as regards the approach of the foe in the shape of disease? The objection to a daily analysis can only be on the score of expense. If in the course of a series of analyses conducted on the ordinary simple lines a water should show a departure from its normal character, further more elaborate investigation

might be called in to elucidate the point, just as the signal fired by a sentry calls out the guard. Water companies and authorities think nothing of the employment of an extra labourer now and then, and yet they seem to view with horror, and as something altogether unnecessary, the idea of appointing a chemist whose duty it would be to stand on guard and to give them instant notice of the first approach of danger. I know that in speaking thus plainly I lay myself open to the charge of trying to make a case for my professional brethren as well as myself. Well, let that be so to those who choose to lay this to my account: it does not alter the fact that even in the case of the vast multitude of people gathered together in the mighty city of London their interests in this respect are only officially safe-guarded by the examination of one sample of water taken occasionally from each company's supply. True it is that the companies themselves have for some time past, since they came to the conclusion that their interests were in jeopardy, taken matters into their own hands, and also that the water consumers, as represented by the London County Council, have made investigations with the result of showing certain defects hitherto unsuspected, and which the companies have wisely remedied in great part. The daily examination of the water supplied should, however, be made systematic, and the results as carefully watched as are the returns by the Registrar-General of the deaths occurring in the community. There can be no shadow of doubt that if the Maidstone water had been subjected to a systematic daily analysis of samples drawn from each source of supply the recent sad disaster would never have happened. The lesson is obvious. Let all authorities, whether companies or councils, take the matter to heart, and insist upon the examination being *daily*, or nearly so. Once a month or once a quarter is insufficient, and would only show a degree of

confidence altogether misleading and dangerous. What a tremendous to-do there is if the dust is not frequently removed from our premises, or if the roads are not swept to our liking—if all the little matters which go to make up modern life are not regularly looked after! And yet we allow one of the most vital of our daily requirements virtually to look after itself.

In the course of my evidence before Lord Balfour's Royal Commission on the Metropolitan Water Supply, I instanced this absurdity, and drew attention to the fact that in the case of our gas, which chiefly concerns our pockets, we spend thousands of pounds annually in making daily examinations as to its quality and quantity. In London alone there is a staff of no less than twenty-three gas examiners, whose daily duty it is (including *Sundays*), at as many stations, to examine and report as to the quality of the gas supplied to their respective districts. There are two superintending gas examiners, one under the City of London and the other under the London County Council, whose duty it is to supervise the above staff; a Chief Gas Examiner, who holds a position equal to that of a judge in regard to technical points in connection with the operations of the examiners and the pleas of the companies, as to the defects, if any, arising from unavoidable causes or accidents; and three Gas Referees, appointed by the Board of Trade, whose duty it is to prescribe and certify from time to time the mode of testing, and the apparatus to be used in making the tests. All this elaborate machinery costs the ratepayers, directly or indirectly, no less than £6,000 per annum merely in regard to that which touches their *pockets*, while, on the other hand, the only money spent in looking after the water supply is a few hundred pounds paid by the Local Government Board on the examination of occasional samples of the water supplied by each of the eight companies per month. What a contrast!

In the case of gas, a large staff of examiners is on duty each day, carrying out the most severe tests, while in the case of the water supply one poor pint or two is tested once a month.

Since the agitation with respect to the proposed purchase of the water companies became almost incessant, they have thought fit, and rightly so, to protect their interests by having the water examined daily in order that they may be able to show that it is above suspicion. In this case, however, the work is not undertaken so much for the purpose of showing any default, should it exist, as to protect the commercial interests of the shareholder. The effect may be good, but the motive is not the true one. The work should be undertaken wholly and solely in the interests of the public, and not to support commercial interests, however good and reasonable they may be.

In regard to the methods of analysis, the biological processes which have come to the front of late years must have a foremost place so far as the ultimate information which may be obtained is concerned, but in regard to the practical utility for the moment as serving to sound the note of warning, the chemical and microscopical methods are far to be preferred, as the latter is capable of giving almost instant notice of the approach of danger. In this respect it is questionable whether any method can exceed in rapidity, simplicity, as well as reliability, the micro-filter method of examination explained in the Appendix, and further illustrated in connection with the examination of the London water supply. By its means, within an hour or so, more or less, according to the skill of the operator and the quality of the water, the character of a sample can be indicated with the utmost reliability, and the test can be repeated again and again upon sample after sample from different reservoirs and filter beds or sources of supply, and the cause of the trouble, when it arises, sought out at once and stopped long before

any serious damage is done; whereas by the biological methods days must elapse before any indications are obtainable. In the latter case it is the old story of locking the stable door after the steed has flown, whilst in the former the groom is always on guard, and the thief is detected at the moment of his approach. In consequence of the simplicity of the micro-filter method the expense of the examination is reduced to a minimum, and therefore there is all the less excuse for its neglect.

The proper course to be pursued, I suggest, is that a sample of water should be examined each day, or nearly so, by the micro-filter process, and that this should be supplemented by a thorough chemical and bacteriological examination undertaken from time to time, the more often the better. By such a systematic search the danger of the propagation of disease by water-carried impurities would be, to all intents and purposes, removed.

CHAPTER XVI.

THE CHARACTER OF THE LONDON WATER SUPPLY.

In the course of a series of analyses which I was called upon to make, certain new features came to light which threw into prominence a point of interest hitherto to a great extent overlooked; this is, that the various matters held in suspension, in presumably pure waters, although small in quantity, are yet often of such a kind as to throw considerable light upon a sample of water, even after the old methods of analysis fail to distinguish the difference between one sample and another.

For the purpose of a recent inquiry into the quality of the water supplied to London, I had the opportunity of making daily analyses of the water of the river Thames at the companies' intakes and of the filtered water supplied by the respective companies drawing therefrom; also the water supplied by the Kent Company, and by the two companies drawing their supplies from the river Lea and New River. (See Diagram N.)

The information thus obtained forms a valuable guide in judging the result of the examination of samples from various sources, as the tabulated results form a useful series of standards for reference.

At first these suspended matters were examined only

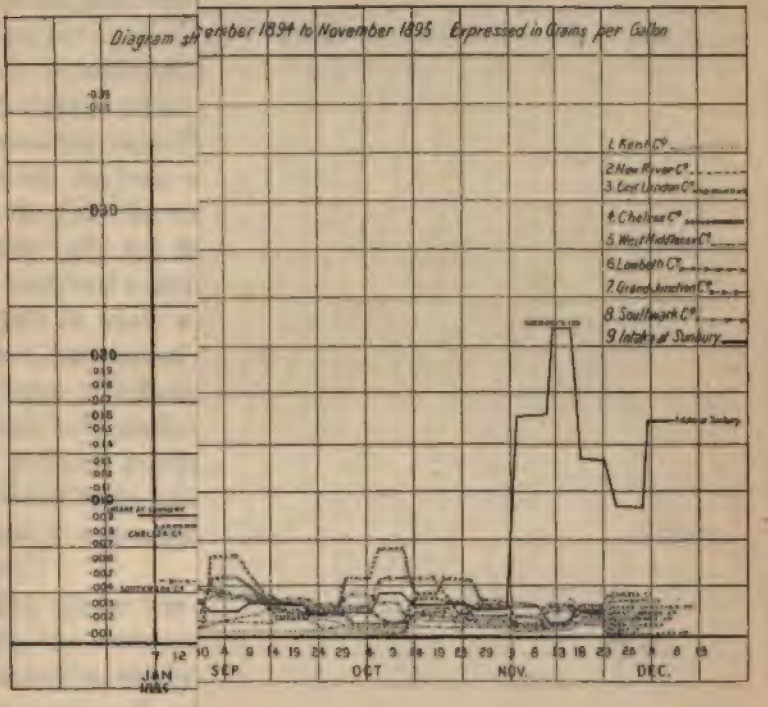


Diagram sh ember 1894 to November 1895 Expressed in Grains per Gallon
1. Kent Cº
2. New River Cº
3. East London Cº
4. Chelsea Cº
5. West Middlesex Cº
6. Lambeth Cº
7. Grand Junction Cº
8. Southwark Cº
9. Intake at Sunbury
JAN
SEP
OCT
NOV.
DEC.

To face p. 260.]

qualitatively, but it soon became apparent, as the work proceeded, that the quantity was sufficient, if properly collected, to admit of exact determinations, and thus more particularly identify them with the unfiltered river water. The collection was therefore conducted on a much larger scale by subsidence in special glass vessels; but it was found that the hard filter papers now in common use formed an admirable medium by which the solid particles could be collected each day and treated with a dilute solution of bichloride of mercury to prevent decomposition, until their microscopical examination, as well as chemical analysis, was made. By this means not only the quality but the exact quantity was estimated, and thus further light was thrown upon the much-vexed question of the analytical examination of water. A modification of this method, in which a specially-constructed micro-filter is employed, has enabled determinations of the relative quantity, in terms of volume instead of weight, of the suspended matters to be made on quantities of water too small even for an ordinary analysis. The results of this method are embodied in the table of analyses under the head of "millimetres of suspended matter in micro-filter from one litre of water."

This process was a development of that adopted for collecting the floating particles for the purposes of microscopical examination, and by this means ensuring the inclusion of the total number of such particles under one cover glass, thus securing greater rapidity as well as accuracy.

Previous to this inquiry it does not appear that any such quantitative methods had been employed. It is clear that either vegetable or animal substances may be quantitatively indicated in terms of carbon, nitrogen, ammonia, and so forth; but such methods of expression, though valuable under certain circumstances, convey but little idea of their relative character, or whether they are in

a fresh and wholesome condition or in a state of putrefaction.

The average results of daily analyses during nearly twelve months ending December, 1895, are given in the table on page 266.

It will be noticed that the average quantities of suspended matters present in the Kent, West Middlesex, and New River supplies were practically identical, namely, 0·0011, 0·0010, and 0·0011 grain per gallon respectively, so that the West Middlesex Company found it possible to so purify and store the water that in this respect it bears comparison with waters which are generally accepted, in view of their source, as beyond suspicion. This quantity may therefore be looked upon as that unavoidably due to rust and dust, and forms a standard whereby to judge the quality of the remaining supplies. Taking the average quantity of suspended matter found during this inquiry in the water supplied by the Southwark, Lambeth, Chelsea, Grand Junction, and East London Companies as 0·0033 grain per gallon, and deducting therefrom the 0·0011 unavoidable or rust and dust matters, found as above, we have 0·0022 chemically dry grain per gallon as obviously avoidable suspended matters present in the filtered water supplied to consumers.

How far this factor would have been increased had such estimation of the suspended matters been made during the bad season of November and December, 1891, it is difficult to judge; but from the improvement effected in the colour of the water, as well as in its analytical character, it is open to the assumption that the suspended matters largely exceeded those present during 1895.

The table on page 304 shows the relative quantity of suspended matters present in the various supplies when determined gravimetrically and by the micro-filter.

From this table it will be seen that there is roughly an

indication of the quality of the suspended matter from the ratio of mm. in micro-filter per litre of water to grains of actual suspended matter per gallon; thus the average of the Kent Company's water for the six months ending November, 1895, gave a ratio of 0·0023 grain per gallon per mm. in the micro-filter; in like manner the New River Company showed a ratio of 0·0033; the West Middlesex, 0·0022; the Chelsea, 0·0052; the East London, 0·0042; the Grand Junction, 0·0057; the Lambeth, 0·0052; and the Southwark and Vauxhall, 0·0056. From this it is seen that when the water is purer the weight of suspended matter per unit volume is least—a fact which is evident on microscopical examination; as in the purer waters only a few fibres with a little *débris* were generally present, in contrast with numbers of particles of *débris* and decaying organic matter, with numerous diatoms, &c. in the case of those waters which bear the least resemblance to the Kent.

In the course of twelve months' determinations of the quantity of suspended matters present in the Kent Company's supply during 1895, I found that the average was 0·0011 grain per gallon. This quantity I have ascribed to unavoidable rust and dust, and it may be safely concluded that any suspended matter less in quantity than this amount may be neglected as of no importance.

My own experience with many waters leads me to think that no serious notice need be taken of any quantity less than 1 mm. per litre, equal to 0·004 grain per gallon, as shown above, or even a larger quantity, unless it is observed there is definite microscopical evidence of objectionable contamination and the chemical analysis shows a questionable state of things.

The chemical examination of the character of the suspended matter gave very remarkable results. For the purpose of this comparison the dry matters obtained from the water, either

by natural subsidence or filtration, were examined for the nitrogen present in combination with the organic matter. The average percentage quantity found is set out in the following table and Diagram O :—

Table LIV.

Nitrogen per cent. on Volatile Organic Matter.

Chalk	Kent		2·12
Thames	Southwark	3·44	3·27
	Lambeth	3·42	
	Chelsea	2·97	
	Grand Junction	3·66	
	West Middlesex	2·86	
New River	New River		2·86
Lea	East London		2·97
Thames Intakes	Sunbury		4·06

For comparison, the following results of the estimation of the quantity of nitrogen present in known samples of polluted mud are given :—

Table LV.

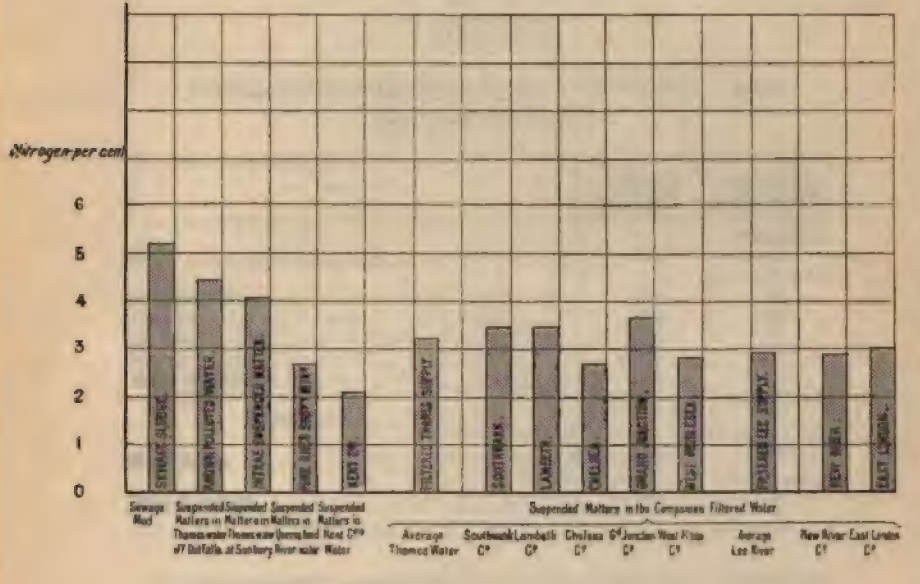
Sewage mud	5·20
Known polluted river mud	4·40
Suspended matter in Thames at Sunbury	4·06
Pure river mud from the Fitzroy River, Queensland	2·70

These results clearly point to the conclusion that, apart from the question of quantity, the suspended matters present in three of the companies' filtered supplies approximated more or less nearly in character to those in the unfiltered river waters at the companies' intakes.

Diagram O.

LONDON WATER SUPPLY.

Diagram showing Percentage of Nitrogen in Volatile (Organic) Matters held in Suspension in Various Waters, &c.



To face p. 261.]

MICROSCOPICAL CHARACTER OF THE SUSPENDED MATTERS.

The conclusion drawn from the consideration of the relative chemical character of the suspended matters in the unfiltered river water, compared with those in the filtered supplies, is borne out by the results of the daily microscopical examination of all samples collected, the average results of which are set out in the condensed table below.

TABLE LVI.

*Percentage Number of Samples returned as "Objectionable" * by the Microscopic Examination.*

	Samples examined.	Returned as objectionable.
		Per cent.
Kent	284	18
Southwark	286	47
Lambeth	284	34
Chelsea	282	22
Grand Junction	285	25
West Middlesex	285	24
Average	..	30
New River	286	21
East London	285	30

* "Objectionable" samples are those which contained a comparatively large quantity of *débris*, microscopic eels (anguillulæ), &c., decaying *débris* infested with bacteria, the larger infusoria, such as paramecium, rotifera, &c., epithelium scales, &c.

These percentages were then calculated into total quantities of objectionable matter present on the actual estimation of the weights of suspended matters found, and are thus set out in column 4 of the following table.

TABLE LVII.

Company.	Average suspended matter.	Microscopical examination of objectionable matters.		Organic nitrogen in suspended matters.			Average number of microbes per c.c.	Average oxygen absorbed by the dissolved matters from permanganate in four hours. Grains per gallon.
	Grains per gallon.	Percentage in samples.	Grains per million gallons.	Per cent.	Grains per million gallons.	Equal to organic matter containing 4·1 per cent. of nitrogen, as in Thames at Sunbury. Grains per million gals.		
Kent	0·0011	18	198	0·84	9	220	90	0·018
New River.....	0·0011	21	231	1·44	16	390	130	0·041
West Middlesex ..	0·0010	24	240	1·43	14	341	130	0·072
Chelsea	0·0027	22	594	1·87	52	1,268	139	0·064
Grand Junction....	0·0023	25	575	2·06	47	1,146	170	0·069
East London	0·0023	30	810	1·35	36	878	277	0·060
Lambeth.....	0·0033	34	1,122	1·86	61	1,488	294	0·071
Southwark.....	0·0056	47	2,632	1·68	94	2,293	352	0·078
Intake at Sunbury..	0·5360	81	434,160*	1·01	5,414	132,049	16,061	0·128

* NOTE.—The microscopical examination includes, with the organic, the mineral matter, which is proportionately larger in the case of the intake waters than in the filtered supplies; hence the objectionable matters appear to be greater by the microscopical examination than those estimated by the nitrogen, which relates solely to organic matter.

The practically complete coincidence between the various methods of examination—namely, the physical, as the estimation of the weight of the suspended matters may be called; the chemical and microscopical examination of their character; the biological examination as to the actual number of bacteria present in a given sample of water; and the strictly chemical examination as to the quantity of oxidisable organic matters dissolved in the water—is very striking.

The unfiltered river water contained a mass of matters of generally indefinite character included under the head of *débris;* but, in addition to these, certain noticeable features were distinct, amongst which the diatomaceæ were predominant; entozoic worms, various dyed and undyed textile fibres, such as wool, cotton, silk, &c., were not infrequent, together with numerous infusoria and bacteria.

The results of the examination of the filtered supplies indicated the frequent presence of all these substances, and in the majority of cases it would have been difficult for a careful observer to conclude from the examination of equal quantities of the preparation under the microscope whether it was drawn from the unfiltered river water or from one of the filtered supplies. Diatoms were always present, and not infrequently anguillulæ also; but the most noticeable and objectionable feature was the frequent presence of fragments of matter in a state of decomposition and swarming with bacteria. The presence of such particles cannot be accepted as inevitable in the case of a pure water supply, as, if the filter-beds are properly worked, it should be impossible for such matters to pass them, whilst if their presence be due to dust getting into the pure-water reservoirs, evidently greater care should be taken to keep them clean. That a particle of dust might be so introduced is not to be doubted, in view of the fact that on a few occasions the Kent supply was found to contain such matters in small quantities, but evidently accidentally so, as compared with their more frequent presence in larger quantities in the filtered river waters.

From the results of this work, it is clear that much more may be learnt from the proper collection and examination of the suspended matters, however small, in a sample of water than has hitherto been supposed, and I venture to suggest that in future all samples of water should be so examined.

A great point has been made in recent years of the number of bacteria present in a water, but from the experience now obtained it would seem as if the number of bacteria depended more upon the quantity of suspended matter than on any other factor.

Considerable differences have been obtained in the estimation of the number of bacteria by different observers. It would now seem possible that these differences are occasionally due to the fact that in one sample certain particles of decaying matters may have been present, although absent in another—a result which would account for many hundreds, if not thousands, of colonies being obtained by one experimentalist and but few by another, quite apart from the known differences due to varying methods of procedure, temperature, &c.

BACTERIOLOGICAL EXAMINATION.

The examination of the daily samples of water for the number of bacteria, as determined by the number of colonies developed on gelatin plates, yielded interesting results, and afforded further evidence of the improvement effected in the various filtered supplies.

The following is a condensed tabular statement of the average number of microbes present in the water collected from standpipes in various parts of the respective companies' districts.

TABLE LVIII.

Month.	Kent.	Southwark.	Lambeth.	Chelsea.	Grand Junction.	West Middlesex.	New River.	East London.	Sunbury.
1895									
January	89	838	793	127	111	128	274	395	15,135
February	90	545	131	161	201	92	194	318	29,308
March	122	818	238	165	135	294	251	556	29,844
April	135	325	286	188	253	135	114	151	7,080
May	73	170	88	339	284	142	145	78	5,664
June	92	199	204	158	181	231	83	602	16,013
July	79	142	102	95	263	113	83	163	10,774
August	112	164	838	108	119	96	98	123	4,813
September	31	164	124	71	113	80	44	88	2,884
October	40	78	59	61	43	54	56	76	9,900
November	139	427	366	55	169	65	92	494	45,263
Average	90	352	294	139	170	130	130	277	16,061

In 1891-92 the following average results were obtained:—Kent, 4,795; Southwark, 4,594; Lambeth, 4,626; Chelsea, 3,091; Grand Junction, 2,612; West Middlesex, 2,534; New River, 2,299; East London, 3,387; Sunbury, 179,601.

Having thus reliable data for comparison as to the bacteriological improvement which took place in the quality of the water between the years 1892 and 1895, it will be interesting to glance at the still further improvement during the course of the latter year, and of the relation which existed between the quality of the intake waters and the filtered supply.

It will be noticed that the company which supplied water containing the largest quantity of suspended matters—viz., the Southwark and Vauxhall—supplied an average of 352 microbes per cubic centimetre of water throughout the year, this being the largest number of any of the companies. In January the monthly average was 838, which gradually decreased during the year to 78 in October, but unfortunately rose again to 427 in November, corresponding to the rise of

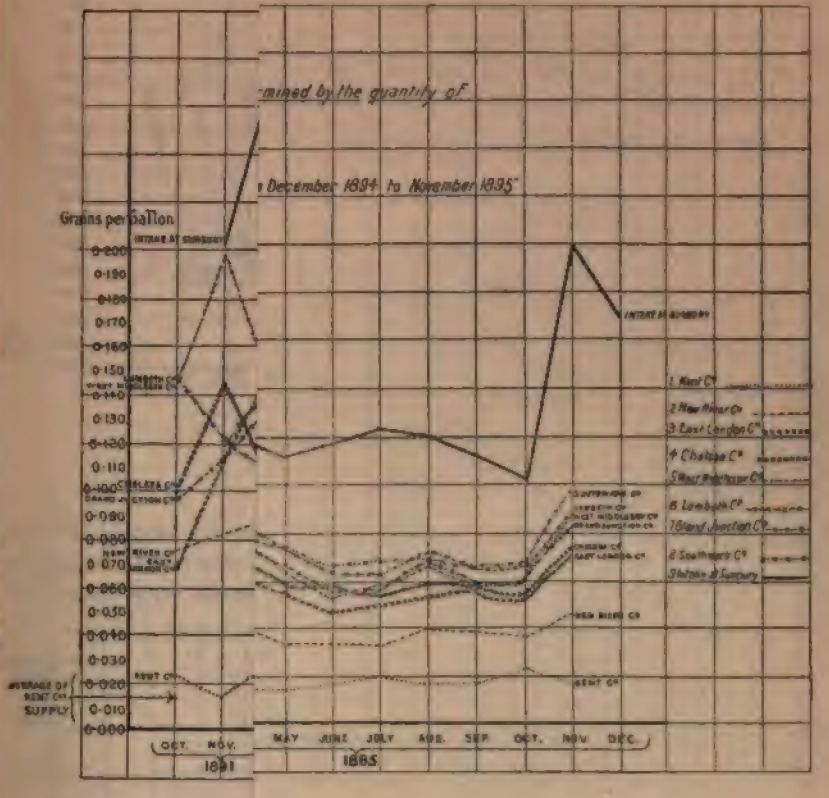
microbes in the Sunbury river water of from 9,900 in October to 45,263 per cubic centimetre in November.

The relative value of the various methods of estimating the organic matter in water—viz., the organic carbon and nitrogen or "organic elements," the albuminoid ammonia, and the oxygen absorbed—has been noted in connection with the series of analyses under discussion. The results of twelve monthly averages of daily analyses made during 1892 (which period is selected in preference to 1895, when there was a break in the continuity of the analyses as regards organic elements and albuminoid ammonia) has shown that the oxygen-absorbed method, as standardized by the Society of Public Analysts, has been found to give the most concordant factor all through. (See Diagrams P, Q and R.)

COMPARISON OF THE PRESENT LONDON SUPPLY WITH THE PROPOSED SUPPLY FROM WALES.

In order that the exact position of the present supply may be clearly understood, so far as regards the question of relative quality and the extent to which an improvement might be anticipated in the event of the Welsh water being brought to London, the following considerations arising from the comparison of the analyses of the water at present supplied to London with those of the Welsh waters collected by myself in May, 1894, will be of interest.

In the following table the analytical factors in each case are placed side by side, so that the specific differences may be seen at a glance. The figures representing the Welsh waters are averages of the samples drawn from the rivers Usk, Edw, Yrfon, Wye, Towy, Ithon, and Clywedog, which were, of course, unfiltered. Those representing the present filtered river water supplied to London are averages of the Southwark, Lambeth, Chelsea, Grand Junction, West Middlesex, and



To face p. 270 (No. 1).]

Diagram Q.

LONDON WATER SUPPLY.

Diagram showing the Relative Quantities of Organic Matters present in the Water Supplied by the respective Companies from October, 1891, to December, 1892, as determined by the Quantity of total Organic Elements (Carbon + Nitrogen).

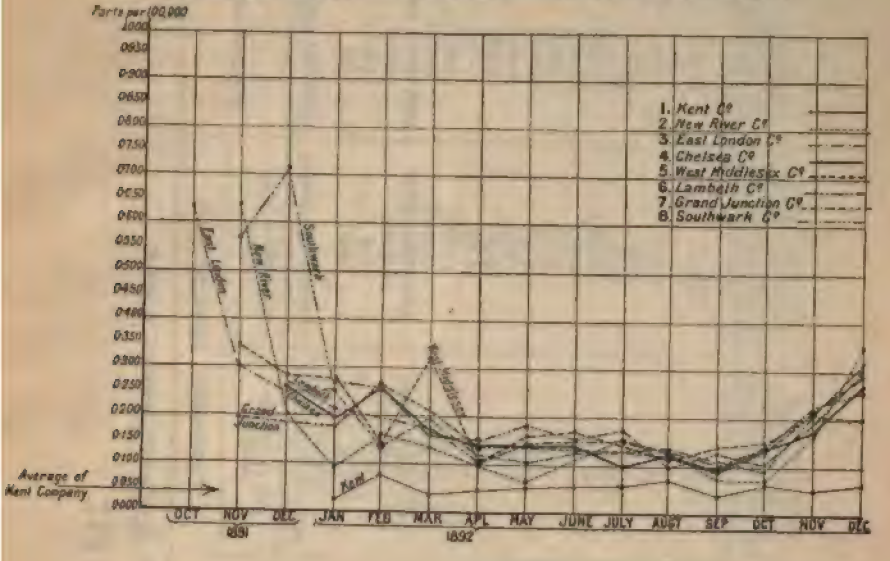


Diagram R.

Diagram showing the Relative Quantities of Organic Matter present in the Water Supplied by the respective Companies from October, 1891, to December, 1892, as determined by the Quantity of "Albuminoid Ammonia."

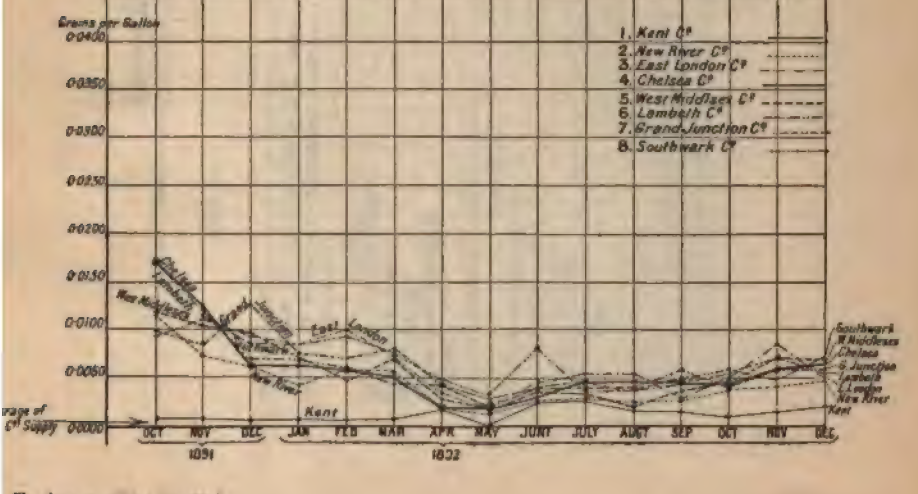


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Table LIX.

Average Results of Analyses of Welsh and London Waters.

	Welsh water, unfiltered.	London supply. Filtered river water.		Kent Company.
		Summer, May to October.	Winter, November to April.	
Appearance (on examination in 2-ft. tube)	Generally clear and bright.	Generally clear and bright.	Occasionally turbid	Clear and bright
Colour by Lovibond's tintometer scale:—				
Units of red	0·4	0·3	0·3	0·0
,, yellow	1·0	0·7	0·9	0·0
Odour at 100 deg. Fahr.	None	None	None	None
Phosphoric acid	Very slight trace	Very slight trace	Very slight trace	Very slight trace
Free ammonia	0·0003	0·0002	0·0004	0·0000
Albuminoid ammonia	0·0033	0·0045	0·0055	0·0012
Chlorine	0·68	1·34	1·32	1·64
Oxygen absorbed in fifteen minutes	0·018	0·035	0·044	0·010
,, ,, four hours	0·048	0·057	0·079	0·018
Nitrogen as nitrates, &c.	0·022	0·128	0·258	0·401
Organic carbon (parts per 100,000)	0·091	0·090	0·163	0·057
,, nitrogen ,, ,,	0·032	0·038	0·036	0·017
Total organic elements (carbon + nitrogen)	0·123	0·128	0·199	0·074
,, solids	4·3	19·3	23·9	28·6
,, hardness	3·1	12·5	17·0	19·5
Permanent hardness	1·6	4·2	4·2	5·4
Cultivation tests by gelatine plates, number of colonies per cubic centimetre	26	167	298	90
Microscopical examination of matters in suspension	Vegetable *débris*, diatoms, organisms.	Vegetable *débris*, diatoms, organisms, &c., in comparatively large quantities.	Vegetable *débris*, diatoms, organisms, &c., in comparatively large quantities.	Few fibres and occasional organisms.

East London. These, however, are given in two columns, one for average summer quality and the second showing average winter quality. For comparison as a standard the Kent Company's average supply is added.

On carefully examining the results, it will be found that the filtered river water supplied during the six summer months to London contains practically identically the same amount of organic carbon and nitrogen as that present in the unfiltered Welsh waters, viz., 0·128 part per 100,000 against 0·123, whilst during the six winter months it is only half as much again, viz., 0·199.

The oxygen absorbed from permanganate is a little more, viz., 0·057 instead of 0·048 during the summer, but only a little more than half as much again, viz., 0·079 grain per gallon during the winter. In like manner the "albuminoid ammonia" in the Welsh water averages 0·0033 against 0·0045 and 0·0055 in the respective summer and winter London supplies, excluding the Kent. The colour of the water when viewed through a 2-ft. tube was on an average even more in the case of the Welsh water, viz., 1·4 against 1·0 and 1·2 in the case of the London supplies.

From this comparison of the average results of nearly 3,000 analyses, it is evident that the organic impurity of the unfiltered Welsh water is a little less than that in the average filtered London water, and the inquiry naturally follows as to the specific differences which exist. This is undoubtedly due to two things: First, the quantity of the solid matter in solution, principally salts of lime, giving the London water its great hardening properties; and, secondly, the comparatively large quantity of floating particles, on which, as has been shown, the number of microbes present to a great extent depends.

The unfiltered Welsh water examined on the spot contained 26 microbes per cubic centimetre, whilst the average

London filtered waters drawn from street hydrants contained in summer 167 and in winter 298, the Kent supply containing 90. Of course, it will be noted that these figures refer solely to the number and not to the character of the microbes.

THE EFFECT OF SOFTENING THE PRESENT SUPPLY.

The suggestion has been repeatedly made that the excessive quantity of carbonate of lime in the London water should be removed by the adoption of the well-known Clark's process, and it is only natural to inquire as to what would be its effect upon the present filtered river water, not only in removing the excess of carbonate of lime, and thus effecting an enormous improvement in the commercial value of the London water, but also in assisting in the process of purification. With the view of testing this question, certain experiments have been made on one of the best London waters, viz., that of the New River Company, in order that the percentage reduction, if any, which might be brought about in the quantity of dissolved as well as undissolved impurity might be ascertained.

The results of these, which are stated in Table LX., p. 274, are perfectly definite, and show that even in the case of the New River supply the reduction of dissolved organic impurity was equal to 25 per cent., as shown by the oxygen absorbed, whilst 64 per cent. of the total hardness was removed and 87 per cent. of the bacteria, and with these the whole of the matters in suspension.

On applying these results to the average analytical figures given below, it will be found that the "albuminoid ammonia" in the summer supply would fall, by the adoption of the process of softening, from 0·0045 to 0·0034, or identically the same quantity as that in the unfiltered Welsh supply, whilst

Table LX.

Experiments to Ascertain the Effect Produced on the Impurities of the New River Supply by the Process of Softening.

Date.	Description.	Examination in a 2-ft. tube.				Odour at 100 deg. Fahr.	Phosphoric acid.	Ammonia.		Chlorine.	Oxygen absorbed in		Total solids.	Appearance on ignition.	Hardness.		Cultivation tests by gelatin plates. Number of colonies.	Microscopical examination of matters in suspension.
		Appearance.	Colour by Lovibond's tintometer scale.					Free.	Albuminoid.		15 minutes.	4 hours.			Total.	Permanent.		
			Red.	Yellow.	Blue.													
1895.																		
Dec. 16	Untreated water ..	Clear	0·1	0·5	—	None	V.S.T.	0·0003	0·0059	1·30	0·029	0·045	23·4	S.B.	17·4	4·2	96	0·3 mm. Tangled mass of fibres, diatoms, bacteria, &c.
	Treated with 9·4 per cent. of saturated lime water.	,,	—	0·3	—	,,	,,	0·0003	0·0047	1·30	0·024	0·037	10·6	,,	5·4	4·0	12	Trace. Few vegetable fibres, organic *débris*.
,, 18	Untreated water ..	,,	0·1	0·6	—	,,	None	0·0003	0·0082	1·30	0·038	0·051	25·2	,,	17·4	3·8	110	Slight trace. Few cotton and other fibres.
	Treated with 9·4 per cent. of saturated lime water.	,,	0·0	0·4	—	,,	,,	0·0003	0·0069	1·30	0·025	0·049	11·0	,,	5·0	4·2	6	Very slight trace. One or two fibres.
,, 20	Untreated water ..	,,	0·1	0·6	—	,,	,,	0·0002	0·0102	1·25	0·030	0·064	24·4	,,	17·2	4·5	60	Very slight trace. Few fibres and little *débris*.
	Treated with 9·4 per cent. of saturated lime water.	,,	0·0	0·4	—	,,	,,	0·0002	0·0068	1·30	0·020	0·028	13·8	,,	8·5	4·5	16*	Very slight trace. Little *débris*.
	Average per cent. reduction.	—	100	35	—	—	—	Nil	23	—	—	25	—	—	64	—	87	

* After fifteen days gelatin still solid. Three moulds and few colonies.

the winter supply would be improved to the quality of the present summer supply; that the oxygen absorbed in four hours would fall from 0·057 to 0·043 in summer, and from 0·079 to 0·059 in winter, against 0·048 in the Welsh water, or a yearly average of only 0·003 grain per gallon in excess; that the organic carbon and nitrogen would be less in proportion, whilst practically the whole of the "suspended matters" would be removed, and with them 87 per cent. of the bacteria, thus reducing the summer number of microbes from 167 to 21, and the winter from 298 to 38, against 26 in the Welsh water, or an annual average difference of + 3. In addition to these enormous improvements the hardness would be reduced in summer from 12·5 deg. to 4·4 deg., and in winter from 17·0 deg. to 6·1 deg., or an annual average of 5·2 deg. against 3·1 deg., which was the average hardness of the Welsh waters as examined in May, 1894.

It would therefore seem that, by the adoption of the system of softening, the present supply, in respect of its chemical quality and number of bacteria, would be improved to a degree comparable with that of the Welsh sources.

CHAPTER XVII.

THE ACTION OF SOFT WATER UPON LEAD.

THE quality of dissolving lead shared by many upland waters, as those supplied to several of the larger towns in the north of England, is a subject that has long engaged attention in this and other countries; and the cause has of late years been the subject of anxious inquiry, especially with a view to the determination of the methods which must be adopted to prevent lead poisoning. This has been more particularly the case since 1886, when abundant lead poisoning was found in Sheffield to result from the use of one of the moorland supplies to that town. Since that time lead poisoning, also due to upland water supply, has been recognized in a number of other communities, including Bradford, Wakefield, Batley, Huddersfield, Shipley, Morley, and Keighley, and one or other method of treatment has already been adopted in all these towns except Huddersfield and Batley. In the case of the former town, it has been found necessary to exclude from domestic use some of the more actively plumbo-solvent tributaries.

It has been found that, whereas all waters act to some extent upon new lead surfaces, the distribution of hard waters through lead pipes is not generally attended with risk, for the reason that a protective coating is quickly formed on the lead surface exposed to the water. This pro-

tective power is not shared by rain or distilled water, or by the greater number of the very soft waters which are obtained from moorland sources; and in respect of those moorland waters which have an acid reaction, the ability to dissolve lead is always strongly marked, even to the extent of constituting a grave danger to health. These soft acid waters are chiefly met with where the gathering ground is peaty; but since more or less water of a different character—such as spring water—is usually included in moorland supplies, the ability to attack lead possessed by the peat-derived water is often neutralized by qualities possessed by the spring water, and the mixture is free from the risk referred to. In such cases, however, the inability of this mixture to attack lead is dependent on the relative proportions of the various kinds of water which constitute the mixture; and inasmuch as these are liable to great variations due to seasonable conditions, it is found that the mixture may be at one time inoperative upon lead although at other times operative.

It appears from a report of the Medical Officer of the Local Government Board, issued in 1895, that the action of water upon lead is of two kinds: the one leading to solution of the lead, the other to its erosion and deposit in a loose powdery form, readily swept away by the current in a pipe, and conveyed to the consumer.

The actual cause of this solvent action is little understood. It is by some ascribed to the presence of acids derived from the decomposition of vegetable substances, such as exist in peat and moorland ground generally, and the fact that a slight addition of calcareous matter is sufficient to remove the plumbo-solvent action would appear to confirm this view. Such, however, could not be the reason in the case of recently fallen rain water or of pure distilled water, both of which act energetically on lead. According to Miller, the necessary conditions are combined action of air and pure water. In

this case the surface of the lead becomes oxidized, and the oxide is dissolved by the water. By the absorption of carbonic acid hydrated carbonate of lead is formed, which is deposited in silky scales. The corrosion is increased by the presence of chlorides or nitrates, but diminished by sulphates, phosphates and carbonates, the oxide of lead being scarcely soluble in water containing these salts.

But, although the cause of the solvent action is obscure, nevertheless remedial measures can generally be successfully employed. The removal of lead pipes from a town in which they already exist, and their substitution by other materials, is scarcely practicable; but it has been found that the use of various substances in small quantities will in most cases effectually remove the danger. The mixing of spring, or of more or less hard or calcareous, water with the moorland supply has been shown above to be uncertain; and, generally, remedial measures are not applicable indifferently, but the particular remedy best adapted for a given water must be found by experiment, and by consideration of the local circumstances. At Sheffield and Bradford water has been deprived of its dangerous condition by the addition of comparatively trifling amounts of chalk, increasing the hardness by some one and a half degrees. At Wakefield a similarly successful result has been attained by the use of carbonate of soda. In other places the desired result has been produced by filtration through calcareous sand. In some cases the mere passage of the water through an aqueduct of sufficient length will furnish enough lime to destroy the solvent action upon lead. The water of Loch Katrine, for instance, is powerfully plumbo-solvent, but loses this character entirely in its passage to Glasgow. In the case of Oldham, again, great benefit has been derived from passing the water through numerous settling tanks constructed on the streams which feed the reservoirs, and then decanting it from

reservoir to reservoir several times before passing it on to the town.

It has been stated by some that the deposit formed in lead pipes by the previous passage of hard water is an effectual safeguard against attack by pure soft water afterwards admitted; and that therefore it would be quite safe to furnish a moorland water supply to a town which, like London, has for many years had hard water passing through its pipes. This view, however, I believe to be erroneous, as the protection thus afforded is only temporary in the case of waters having an acid reaction. Besides, new houses with new lead pipes, through which there has been no previous flow of hard water, are daily erected.

"Many men, many opinions," applies to considerations affecting the analysis or the purification of water more particularly, and various experts have given expression to the most widely divergent views on this special question of the action of lead on water, and the means to be employed to obviate it. This is, no doubt, due to our want of precise knowledge on the subject, and to the fact that a water examined by one observer is found to act strongly on lead, whilst one of apparently exactly similar character in all other regards, but from a different, although like, source, has been found by another observer to be quite without such action. Mere storage for a short time will frequently remove such power from a water which, when first collected, possessed it in a marked degree. It will be seen that the question is very difficult, and generalising would appear at present unwise.

CHAPTER XVIII.

THE ABSORPTION OF ATMOSPHERIC OXYGEN BY WATER.

Having established that the friendly or non-putrefactive organisms which bring about the destruction of the effete matters in foul waters cannot continue their beneficent work unless there is a plentiful supply of oxygen dissolved in the water, it becomes necessary to ascertain the rates at which water will renew the oxygen abstracted from it by the microbes in their life processes. This rate, it will be seen, is a measure of the degree of the rapidity with which aërobic bacteria can multiply and work; and beyond that point it will be useless to expect results without incurring the risk of putrefaction by the agency of the anaërobic organisms. Of course, if it is desired to bring about the destruction of the organic matter by means of the latter (as described in Chapter VI.), instead of by oxidising microbes, the oxygen dissolved in the water is a matter of no importance.

Water dissolves very unequal quantities of the different gases, and very variable quantities of the same gas at different temperatures. One volume of water absorbs, at the temperature stated in the following table—*vide* "Fowne's Chemistry," edited by Watts, twelfth edition, page 148—and under the pressure of 30 in. mercury, the following volumes of different gases measured at 0 deg. Cent. and 30 in. pressure.

TABLE LXI.

Deg. Cent.	Oxygen.	Nitrogen.	Hydrogen.	Nitrogen Monoxide.	Carbon Dioxide.
0	0·041	0·020	0·019	1·31	1·80
10	0·033	0·016	0·019	0·92	1·18
20	0·028	0·014	0·019	0·67	0·90

Deg. Cent.	Chlorine.	Hydrogen Sulphide.	Sulphurous Oxide.	Hydrochloric Acid.	Ammonia.
0	—	4·37	53·9	505	1180
10	2·59	3·59	36·4	472	898
20	2·16	2·91	27·3	441	680
30	1·75	2·33	20·4	412	536
40	1·37	1·86	15·6	387	444

When the pressure increases a larger quantity of the gas is absorbed. Gases moderately soluble in water follow in their solubility the law of Henry and Dalton, according to which the quantity of gas dissolved is proportional to the pressure. At 10 deg. Cent. one volume of water absorbs under a pressure of one atmosphere 1·18 volume of carbon dioxide, measured at 0 deg. C. and under a pressure of 30 in. mercury. The quantity of carbon dioxide dissolved under a pressure of two atmospheres, and measured under conditions precisely similar to those of the previous experiment, equals 2·36 vols. Gases which are exceedingly soluble in water do not obey this law, except at higher temperatures, when the solubility has been already considerably diminished.

It deserves, however, to be noticed that the pressure which determines the rate of absorption of a gas is by no means the general pressure to which the absorbing liquid is exposed, but that pressure which the gas under consideration would exert if it were alone present in the space with which the absorbing liquid is in contact. Thus, supposing water to be in contact with a mixture of one volume of carbon dioxide and three volumes of nitrogen, under a pressure of four

atmospheres, the amount of carbon dioxide dissolved by the water will be by no means equal to that which the water would have absorbed, if it had been at the same pressure of four atmospheres in contact with pure carbon dioxide. In a mixture of carbon dioxide and nitrogen in the stated proportions, the carbon dioxide exercises only one-fourth, the nitrogen three-fourths, of the total pressure of the gaseous mixture = four atmospheres; the partial pressure due to the carbon dioxide is in this case one atmosphere, that due to the nitrogen three atmospheres; and water, though exposed to a pressure of four atmospheres, cannot under these circumstances absorb more carbon dioxide than it would if it were in contact with pure carbon dioxide under a pressure of one atmosphere.

It is necessary to bear this in mind in order to understand why the air which is absorbed by water out of the atmosphere differs in composition from atmospheric air. The latter consists very nearly of twenty-one volumes of oxygen and seventy-nine volumes of nitrogen. In atmospheric air which acts under a pressure of one atmosphere, the oxygen exerts a partial pressure of $\frac{21}{100}$, the nitrogen a partial pressure of $\frac{79}{100}$ atmosphere. At 10 deg. Cent. one volume of water (see the above table) absorbs 0·033 volume of oxygen and 0·016 volume of nitrogen, supposing these gases to act in the pure state under a pressure of one atmosphere. But under the partial pressures just indicated, water of 10 deg. Cent. cannot absorb more than $\frac{21}{100} \times 0{\cdot}033 = 0{\cdot}007$ of oxygen, and $\frac{79}{100} \times 0{\cdot}016 = 0{\cdot}013$ volume of nitrogen. In $0{\cdot}007 + 0{\cdot}013 = 0{\cdot}020$ volume of the gaseous mixture absorbed by water there are consequently 0·007 volume of oxygen and 0·013 volume of nitrogen, or in one hundred volumes of the gaseous mixture, thirty-five volumes of oxygen and sixty-five volumes of nitrogen. The air contained at the common temperature in water is thus seen to be very much

richer in oxygen than ordinary atmospheric air. This property of water to absorb oxygen from the air more readily than nitrogen has been applied to the preparation of oxygen for industrial use.

Air is pressed into water by means of a force pump, and the gases which escape on diminishing the pressure are subjected to the same treatment eight times in succession, by which time nearly pure oxygen is obtained. The following table shows the composition of the gaseous mixture at each successive stage:—

TABLE LXII.

Atmospheric Air.	Composition after Successive Pressures.							
	1	2	3	4	5	6	7	8
Nitrogen 79	66·7	52·5	37·5	25·0	15·0	9·0	5·0	2·7
Oxygen 21	33·3	47·5	62·5	75·0	85·0	91·0	95·0	97·3

In the course of a series of experiments on the condition of the water in the river Thames, I instituted some tests for the purpose of ascertaining the rapidity with which water will take up oxygen from the atmosphere. In these experiments the conditions actually occurring in the river could not necessarily be reproduced; the agitation, influence of wind, and varying ratio of surface to the depth being impossible to gauge with any degree of certainty. By the method adopted, however, a fairly accurate series of results was obtained, applicable to absolutely still water, in which the ratio of surface to depth was practically unity. By this means it was rendered certain that the results could not exceed those which would have been found had the whole of the actual circumstances been brought under control, since any agitation by traffic or wind, or any increase in the ratio of surface to depth, must necessarily have increased the normal rate.

The actual *modus operandi* was as follows:—A quantity of water was boiled in a flask until all the air was expelled.

The flask was then sealed and allowed to cool. When cool the seal was removed and the contents transferred without agitation to open vessels, in which the water was exposed to the atmosphere for periods of time varying from one to ninety-six hours. The quantity of dissolved oxygen was then determined by the usual gasometric method, in which the air is boiled out of the water in a vacuum, and collected over mercury and analysed in the usual way by either exploding the oxygen with an excess of hydrogen, or by absorbing it with pyrogallic acid in the presence of alkali; both methods being used as a check on each other. The special form of air pump (see Appendix) employed for withdrawing the gases from the water was designed by myself on the lines of Macleod's apparatus, and has been found to be most efficient for its purpose, many thousands of determinations having been made by its use in the three laboratories formerly under my charge.

Upwards of 150 estimations were made, and from the figures thus obtained a curve was constructed, showing the rate of absorption for each percentage degree of aëration. These results are shown in the diagram S.

From this it will be seen that a water absolutely free from oxygen dissolved therein will absorb in one hour 10 per cent. of the total possible quantity which it can take at ordinary temperature and pressure, viz., about 1·8 cubic inches per gallon. In two hours it will have taken up 20 per cent. In three hours the quantity of oxygen dissolved will have increased to 26 per cent.; in four hours to 32 per cent.; in five hours to 36 per cent.; in six hours to 40 per cent.; in seven hours to 43 per cent., and so on, until ten hours are required for it to absorb only one-half its total quantity, viz., 50 per cent., the rate decreasing as the degree of saturation increases, until, as it approaches saturation, it takes only a few tenths of one per cent. per hour.

As showing the practical bearing of these results upon the water of the river Thames, we may consider their effect on the tidal portion of the river from Teddington to the Nore. The following table shows the average percentage quantity of oxygen dissolved in the water at fifteen different points at and between these places from July, 1893, to March, 1894 :—

TABLE LXIII.

Average percentage Quantity of Oxygen (saturation = 100) Dissolved in the Water of the River Thames at

Locality.	High Water.	Low Water.
Teddington (above lock)	85·0	
Kew	70·3	85·5
Hammersmith	55·7	78·8
Battersea	42·6	67·6
London Bridge	34·5	51·8
Greenwich	24·6	37·4
Blackwall	22·5	34·3
Woolwich	22·2	30·8
Barking Creek	24·2	30·8
Crossness	43·0	41·6
Erith	39·4	29·1
Greenhithe	38·4	25·1
Gravesend	50·7	39·5
The Mucking	83·6	72·0
The Nore	90·1	89·1

From this table it will be seen that the average aëration at high and low water, between Teddington and Chiswick, is a trifle under 80 per cent. of the total possible quantity.

This decreases rapidly, reaching its lowest point at or about Woolwich, where it is only 26 per cent. From that

point it rises again, until between Gravesend and Southend it is about 75 per cent., and at the Nore 90 per cent. In other words, the water as it flows over Teddington weir is well aërated, and is able to deal with all polluting matters contained in it without suffering any material reduction in aëration, *i.e.*, the rate of absorption from the atmosphere (actual aëration being 85 per cent.) is equal to the rate of consumption by the microbes feeding on the organic impurities. As we proceed downwards it is found that this process abstracts more oxygen than can be supplied at the former slow rate at the higher degree of aëration; and, accordingly, the degree of aëration falls, which fall is accompanied by a corresponding increase in the rate of absorption from the atmosphere, as shown by the foregoing experiments. When the rate is again equal to the necessities of the increased number of organisms feeding on the larger quantity of organic impurities, the balance is once more established, and the aëration remains constant at the lower rate. Further down again the organic impurities becoming less, both by previous oxidation and by dilution, the quantity of oxygen dissolved in the water gradually increases, accompanied by a diminution in the rate of absorption from the atmosphere until the two factors are once more equal and equilibrium is regained.

From these observations it is evident that at Teddington, where the degree of aëration is 80 per cent., the rate of absorption of atmospheric oxygen will be 3·6 tons per hundred million cubic feet per day, and as the sectional volume of the river between that point and Chiswick at *high* water may be taken, according to Professor Unwin, at 250·8 million cubic feet, it follows that this reach of water will absorb nine tons of oxygen in twenty-four hours, or 4½ tons on the assumption that the *mean* water capacity is one-half of that at high water. In like manner each section

of the river is tabulated on the above assumption as follows:—

TABLE LXIV.

Section.	Volume of water (at high water) in million cubic feet.	Rate of absorption tons per 100 million cubic feet per day.	Tons of oxygen dissolved by the water in section per 24 hours.
Teddington to Chiswick	250·8	3·6	4½
Chiswick to St. Paul's Pier	678·6	12·7	43
St. Paul's Pier to Deptford	643·2	21·4	69
Deptford to Woolwich	1099·0	43·8	240½
Woolwich to Barking	480·3	43·8	105
Barking to Crossness	898·7	29·2	131
Crossness to Erith	1155·0	21·9	126½
Erith to Gravesend	6543·0	21·9	716
Gravesend to Southend	34695·0	5·5	949
Total			2384½

These considerations show the enormous forces at work in purifying our streams and rivers, and constitute the real secret of Nature's method in effecting the destruction of effete matters wherever they may be. It must be obvious on the face of it to the meanest capacity that without some such operation the whole world would soon be covered to a considerable depth with rubbish, and life would be insupportable. But by these constant processes of interchange, Nature restores the balance, and man, in common with all animal and vegetable life, continues his way, and except where he wilfully or ignorantly spoils his surroundings, the world is kept clean and wholesome.

We have seen in the past chapters how this oxygen is brought into actual combination with the organic matters by the action of living organisms, and thus by careful consideration of that action, combined with that of the mighty sponge-like power of the water, the whole mystery of Nature's method of purification is made plain. In this we see

but one more instance of the power of science to clear up mystery after mystery. A few years ago it was stoutly denied that rivers had the power of purifying themselves! Then we knew practically nothing of Nature's method. Now that this has been so far revealed to us, it is declared with equal force that not only are effete matters rendered innocuous, but even disease-producing microbes are themselves voraciously devoured by others of like kind, and the formerly much-dreaded bacteria are—and properly so—considered amongst the best friends of man.

CHAPTER XIX.

ANALYSES AND THEIR INTERPRETATION.

When a process of sewage treatment has been adopted it is necessary to watch the operation very carefully, in order to ascertain from time to time whether the work is being effectually carried on. The usual tests by eyesight and smell are of course the first to suggest themselves, and, so far as they go, are undoubtedly of great importance. These, nevertheless, however useful as guides for any particular individual, do not admit of accurate registration in such a manner as to enable a second or third person to make comparison with similar tests instituted by him, and, therefore, some means are required by which this can be done; hence the first necessity for analysis, which in this sense may be looked upon as a process by which quality can be recognised at a subsequent date by the inspection of written records. In the second instance analysis goes much beyond this elementary use as it enables us to ascertain the quantity of invisible and, for the time, inodorous impurities, which may subsequently develop offensive qualities under certain conditions. By chemical analysis we thus measure the invisible, and are able to gauge the ultimate obtainable condition of our effluent.

It is therefore clear that the useful and necessary guides of appearance and smell are insufficient to indicate when matters are in a critical state and the process is in danger of breaking down. Under present working conditions there

may frequently come a time when a filter will require rest, and if this is not given at the proper moment the bed will eventually have to be put out of action for a still longer period than would have been necessary if it had been given a shorter rest for a few days before it became overworked. How, then, can we ascertain the degree of purification which is being effected, and, consequently, the arrival of the critical point when rest becomes necessary? This can only be done by methods of chemical analysis, which, however, need not be of a very extensive character. It is not proposed to describe the ordinary methods of analyses, as these are efficiently dealt with in most modern text-books on quantitative chemical analysis. Special methods of analysis not usually described will be found in the Appendix.

Standards of Purity.

The following standards of purity were recommended by the Rivers Pollution Commissioners appointed in 1868 :—

We recommend that, with certain exceptions in reference to standards *d* and *e*, the following liquids be deemed polluting and inadmissible into any stream :—

(a) Any liquid containing *in suspension* more than three parts by weight of dry mineral matter, or one part by weight of dry organic matter in 100,000 parts by weight of the liquid.

(b) Any liquid containing, *in solution*, more than two parts by weight of organic carbon, or 0·3 part by weight of organic nitrogen in 100,000 parts by weight.

(c) Any liquid which shall exhibit by daylight a distinct colour when a stratum of it one inch deep is placed in a white porcelain or earthenware vessel.

(d) Any liquid which contains, *in solution*, in 100,000 parts by weight, more than two parts by weight of any metal, except calcium, magnesium, potassium, and sodium.

(e) Any liquid which, in 100,000 parts by weight, contains, *whether in solution or suspension*, in chemical combination or otherwise, more than 0·05 part by weight of metallic arsenic.

(f) Any liquid which, after acidification with sulphuric acid, contains, in 100,000 parts by weight, more than one part by weight of free chlorine.

(g) Any liquid which contains, in 100,000 parts by weight, more than one part by weight of sulphur, in the condition either of sulphuretted hydrogen or of a soluble sulphuret.

(h) Any liquid possessing an acidity greater than that which is produced by adding two parts by weight of real muriatic acid to 1,000 parts by weight of distilled water.

(i) Any liquid possessing an alkalinity greater than that produced by adding one part by weight of dry caustic soda to 1,000 parts by weight of distilled water.

(k) Any liquid exhibiting a film of petroleum or hydro-carbon oil upon its surface, or containing in suspension in 100,000 parts, more than 0·05 part of such oil.

The only other standards of purity which have been adopted are those of the three Rivers Boards, viz. :—

1. The Mersey and Irwell Joint Committee, formed in 1891, and having jurisdiction over so much of the River Mersey and any tributaries thereof, above the point of intersection by the southern boundary of the borough of Warrington, as passes through the counties of Lancaster and Chester, or between them, or through or by any of the county boroughs of Bolton, Bury, Manchester, Oldham, Rochdale, Salford and Stockport.

2. The Ribble Joint Committee, formed in 1891, and having jurisdiction over so much of the River Ribble and any tributaries thereof, and of the Rivers Darwen and Douglas, and the streams running into the Crossens Channel, as passes through the county of Lancaster, or through or by the county boroughs of Blackburn, Burnley, Preston and Wigan.

3. The West Riding Rivers Board, formed in 1893, and having jurisdiction over so much of every river or tributary thereof as passes through or by the county of the West Riding of Yorkshire, or through or by any of the county

boroughs of Bradford, Halifax, Huddersfield, Leeds and Sheffield.*

The respective standards adopted by these authorities are as follows:—

Mersey and Irwell Joint Committee:

Oxygen absorbed from permanganate of potash in 4 hours at 80° F. = 1·0 grain per gallon.

Albuminoid ammonia, 0·1 grain per gallon.

Ribble Joint Committee:

Albuminoid ammonia, less than 0·1 part per 100,000, indicates "good" effluents in the absence of other easily observed objections, such as foul smell, excessive turbidity, &c. More than 0·2 parts per 100,000 indicates "bad" effluents in the absence of any special information suggesting an origin other than sewage matter for such ammonia. Others are classed as "fair" or "poor" according to the amount of albuminoid ammonia between these figures. The dividing line between good and bad is usually taken as 0·16 parts of albuminoid ammonia per 100,000, = 0·112 grain per gallon.

The West Riding of Yorkshire Rivers Board:

Oxygen absorbed from permanganate of potash in 4 hours at 80° F. = 1·0 grain per gallon.

The Thames Conservancy Board has not published any standard, evidently preferring to judge every case according to the local circumstances.

Oxygen absorbed.—The quantity of the oxygen absorbed by the organic matter in solution in crude London sewage on an average will vary from about three to four grains per gallon, according to the character of the sewage. It must be noted in passing, that the word "average" is here used as denoting the average quality of the daily flow, and not merely a mixture of samples taken at odd times. If this is done, the

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* See p. xxv. Third Report, Royal Commission on Sewage Disposal, 1903.

strength of the sewage will be found to vary very considerably according to the time of day, rainfall, &c. We may, therefore, take 3·5 grains as a fair average factor for crude London sewage throughout the year as a standard of comparison. The effect of treating sewage chemically by putting precipitating agents into it will be to remove a certain proportion of the matters in solution, in addition to most of the matters held in suspension. The extent to which the matters in solution are affected was shown in the tables in Chapter III. On turning to Table IV. (p. 44) we see very clearly that the strength of the solution of organic matter is very considerable in certain cases, and in these no less than from 90 to 91 per cent. of the dissolved organic matter is thrown down by suitable precipitating reagents; but as the strength of the solution declines the quantity removed by the same means falls to only about 50 per cent., thus clearly showing that the dilution of the sewage is an objection from the point of view of its suitability for chemical treatment. As will be noted, these experiments were made upon a specially prepared solution of meat extract, in order that we might have a fairly definite extractive substance as a standard. In order to ascertain the effect of similar treatment on ordinary sewage, the further trials given in that chapter were made upon simple raw sewage collected throughout the twenty-four hours, so as to show the influence of the varying character of the sewage upon the treatment, and to throw light upon the many discrepancies in the statements made by various experimentalists. In Table III. the same characteristic is shown. The stronger the sewage the greater the percentage removal of the organic matters in solution, as shown by the quantity of oxygen absorbed by those remaining in solution.

As showing how the monthly average quantity of dissolved impurities, as indicated by the oxygen absorbed, may vary during the year, apart from the daily variation, the following

table is of interest. Each factor is the average of daily analyses of samples collected day and night at intervals of two hours, so as to ensure accurate results:—

TABLE LXV.

1894.	Northern outfall, Barking Creek.	Southern outfall, Crossness.
January	3·396	3·418
February	3·415	3·474
March	3·283	4·050
April	3·172	3·658
May	3·269	3·614
June	2·924	3·952
July	3·013	3·721
August	2·814	3·554
September	2·856	3·799
October	3·221	3·951
November	2·942	3·420
December	3·186	3·892
Average	3·124	3·709

At certain times the effects of large quantities of blood let into the sewers from the cattle market, Deptford, which formerly used to flow direct into the river at that point on the southern side of the Thames, and contribute greatly to the usual amount of impurity, are very noticeable, the quantity of oxygen absorbed rising to abnormal figures. As I have already shown, the greater the impurity the better the effect of the treatment, and thus the process adopted has been able to cope effectually with the increased amount.

For comparison with the above, samples of sewage from the works, Sutton (Surrey), where the sewerage is on the "separate system," were found to absorb an average quantity of oxygen equal to 4·29 grains per gallon, so that the effect of this system is to keep the sewage a little stronger. In the case of the Southern (London) outfall, the average quantity of oxygen absorbed for the year 1894 was 3·115 grains per gallon (see Table XLIIIA. p. 215), thus showing a reduction of 16 per cent., and in the case of the stronger sewage at Sutton the re-

duction was 32 per cent. But on turning to the result of biological filtration at the Northern Outfall Works at Barking Creek (p. 62), we find that the average reduction was nearly 80 per cent., and in the case of the Sutton experiments (p. 83), 89 per cent.

In the case of river water, such as that of the Thames during the period from July, 1893, to March, 1894, the oxygen absorbed varied according to the following table. The figures are the results of daily analysis during that period, which includes phenomenally dry and wet seasons :—

TABLE LXVI.

Oxygen Absorbed.

	Grains per gallon.	
	High water.	Low water.
Teddington, above lock	0·162	—
Kew Bridge	0·179	0·161
Hammersmith	0·197	0·173
Battersea Bridge	0·231	0·185
London Bridge	0·273	0·198
Greenwich	0·361	0·252
Blackwall	0·375	0·270
Woolwich	0·377	0·307
Barking Creek	0·381	0·349
Crossness	0·353	0·387
Erith	0·294	0·400
Greenhithe	0·198	0·302
Gravesend	0·164	0·213
The Mucking	0·101	0·126
The Nore	0·052	0·068

Carrying the comparison one step farther, we may now look at the average results of the daily analysis, made under my direction, of the London water supplied by the various companies. It will be interesting to remember that the water in the Thames at Sunbury is that practically taken by all the respective companies drawing their supplies from that river, the different positions of their intakes having but little effect. These will complete the sequence of comparisons for ascertaining the degree of impurity in any given sample.

Table LXVII.

Average Daily Quantity of Oxygen Absorbed (by the Dissolved Matters) from Permanganate in four hours at 80 deg. Fahr., during the twelve months ending December, 1895.

Description of water.	Grains per gallon.
River Thames at the intakes at Sunbury	0·128
Kent Company	0·018
New River	0·041
West Middlesex	0·072
Chelsea	0·064
Grand Junction	0·069
East London	0·060
Lambeth	0·071
Southwark and Vauxhall	0·078

Summarising these results in their order, we have the following very interesting and instructive table:—

Table LXVIII.

Description of water.	"Oxygen absorbed" in four hours. Grains per gallon.
Kent Company's deep well in chalk	0·018
New River, partly spring, well, and river	0·041
Lee River, filtered supply	0·060
Thames Company's average filtered supply	0·071
Thames, unfiltered, the Nore	0·060
,, ,, the Mucking	0·113
,, ,, Sunbury (companies' intakes)	0·128
,, ,, Teddington (above lock)	0·162
,, ,, Kew	0·170
,, ,, Hammersmith	0·185
,, ,, Gravesend	0·188
,, ,, Battersea Bridge	0·208
,, ,, London Bridge	0·235
,, ,, Greenhithe	0·250
,, ,, Greenwich	0·306
,, ,, Blackwall	0·325
,, ,, Woolwich	0·342
,, ,, Erith	0·347
,, ,, Barking	0·365
,, ,, Crossness	0·370
Average water-carried sewage, London, North	3·124
,, ,, ,, ,, South	3·709
,, ,, ,, separate system, Sutton	4·290

If the quality of the water of the river at Southend is taken as being equal to the mean of that at the Nore and the Mucking, then we have the somewhat startling but satisfactory result that the water of the estuary at that favourite watering-place is, to all intents and purposes, organically as pure as that supplied after filtration to the consumers of London by those companies drawing from the Thames at Hampton and Sunbury; the quality of which has been described by the late Sir Edward Frankland as equal to the finest drinking water supplied to any community in the world.

Dissolved oxygen.—The exact degree of aëration which an effluent thus kept should maintain is a matter for further experience to determine; but if it does not fall below 50 per cent. of the maximum possible, no evil results need be apprehended. Whenever the aëration of the water of the Thames was found to exceed this minimum, there was no suggestion of nuisance, and fish appeared in the areas which maintained this degree of aëration. If, then, an effluent be added to water in quantity exceeding that which would actually be the case in practice, and the degree of aëration at no time falls below the point indicated, fish-life would be in no way interfered with. Further, the power of a river to purify itself depends upon the degree of aëration maintained; and when this exceeds the figure above mentioned, there is not the least fear of putrefactive processes intervening, but aërobic purification continues, and all remaining organic matter is rapidly oxidised.

A most valuable standard of purity might be arrived at by these means. Suppose, for example, that a mixture of one part of effluent and one part of fully aërated water be allowed to stand in an open vessel of diameter equal to the depth of the liquid, and that the degree of aëration, ascertained daily for a certain number of days, does not fall below an agreed figure to be determined, then such effluent may be safely

admitted into any ordinary stream. In extreme cases, when the only water in the brook is derived in summer time solely from the sewage works, the effluent must of course stand the test without any dilution. The following experiments on these lines with effluents from the Sutton Sewage Works are appended :—

TABLE LXIX.

—	C.c. Oxygen per Litre.	Per Cent. of Maximum possible.
A. 1. Sutton effluent* as received in stoppered bottles—		
Contained	0·91	12·5
After 26 hours	1·40	20·0
A. 2. Effluent as above, aërated by shaking—		
After 2 hours	4·77	68·0
,, 20 ,,	3·30	50·0
,, 3 days	2·38	33·0
A. 3. Effluent as above, with 4 vols. tap water—		
After 2½ hours	2·98	42·5
,, 22 ,,	4·79	70·0
,, 36 ,,	6·09	85·0
B. 2. Sutton effluent, aërated by shaking—		
After 48 hours	4·82	71·0
,, 51½ ,,	3·87	55·0
B. 3. Effluent as above, with 4 vols. tap water—		
After 48 hours	4·29	61·0
,, 52½ ,,	5·10	73·0
Country Stream receiving a Farm Effluent.		
C. 1. Water from river *above* outfall, aërated by shaking and allowed to stand 1½ hour	4·28	68·0
C. 2. Water from river *below* outfall, aërated by shaking and allowed to stand 1½ hour	5·35	85·0
After 67 hours	1·36	21·6
C. 3. Farm effluent, aërated by shaking and allowed to stand 1½ hour	0·91	13·6
After 67 hours	0·20	3·1
C. 4. Tannery effluent,† shaken and allowed to stand for 67 hours	3·80	58·0

* The albuminoid ammonia in this sample was 0·076 grain per gallon.
† Saturated with lime, and consequently sterilised.

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The following diagrams of the results of the determination of the quantity of oxygen dissolved in a series of effluents from tank and beds, and in a mixture of river water and effluent, will serve to show what may be accomplished in this way.

The first diagram (T) shows the percentage of oxygen dissolved in the sample of sewage when it was collected, the quantity of oxygen being necessarily affected by agitation during the collection of the sample and its transference to the laboratory. After the first determination, the results of which are indicated on the first ordinate marked "as received," the sample was shaken up so as to thoroughly aërate it, and then left quiescent for twenty-four hours, when it was examined again. In each case the whole of the oxygen had been utilised, together with that which must necessarily have been absorbed from the atmosphere in the meantime.

The same result was found after the second day, but on the third day the aëration had risen, and on the fourth day it was marked—viz., 27 per cent.

The tank effluents (diagram U) showed a similar sequence, but more marked in regard to the degree of retained aëration.

The effluents from the first bacteria bed (diagram V) showed variable results, but with a higher percentage of retained oxygen; whilst those from the second bacteria bed (diagram W), with two exceptions, contained and retained an aëration factor considerably above that of 50 per cent. of the total possible.

The mixture of river water and effluent from the second bacteria bed (diagram X) in every case gave satisfactory results, the average being over 70 per cent.

Whether the open vessel or closed bottle be employed, the method of analysis to be adopted requires consideration. There are three principal processes at the disposal of the operator—viz., the absolute gasometric, and the methods of Schützenberger and Thresh. These are described in Appen-

dix II. Both the latter have the great advantage over the first named in that the necessary apparatus can be readily carried from place to place, so that the determinations can be made *in situ*. As against this, however, both have been found to be unreliable under certain conditions, the presence of very many substances causing them to yield results which are quite fallacious. For example, an effluent from distillery refuse appeared, when examined by Thresh's method, to contain in solution twice as much oxygen as it was possible for it to dissolve.

During the investigation into the character of the water of the Thames in 1893—94 (page 219), a very large number of samples were examined by all three methods with a view to instituting comparisons between them, and it was found that in highly aërated water at Teddington the results were quite comparable; when the degree of aëration fell, as at London Bridge at high water, to between 20 and 25 per cent., the figures yielded by the two colorimetric methods were far too low; whilst in the case of the Woolwich water, which contained much organic matter, and in which the degree of aëration fell sometimes as low as 3 per cent., the results were quite unreliable. The following table shows the average results of the comparative tests at Teddington and London Bridge, and the percentage deviation of the two named processes from the absolute or gasometric method:—

TABLE LXX.

Station.	Degree of Aëration by				
	Gasometric.	Schützenberger.		Thresh.	
		—	Difference.	—	Difference.
			Per Cent.		Per Cent.
Teddington	86·7	90·4	+ 4·2	88·5	+ 2·1
London Bridge, high water	21·6	17·3	−19·9	11·5	−46·8
London Bridge, low water	29·6	25·1	−15·2	24·2	−18·2

Suspended Matters.—The following table shows the quantity of suspended matters in average London sewage during the year 1894, and that in the effluent after treatment with lime and iron. It must be remembered that in this instance all storm water is included, and as the process has been converted from the original design of quiescent precipitation to one involving continuous flow, the settlement is not so perfect as it would otherwise be :—

TABLE LXXI.

Suspended Matters.

	Grains per gallon.	
	Sewage.	Effluent.
January	38·1	8·9
February	30·2	6·1
March	29·5	7·8
April	30·2	7·2
May	33·5	7·1
June	30·6	6·3
July	36·1	6·6
August	36·1	6·1
September	26·6	5·7
October	35·3	5·0
November	22·5	3·2
December	29·1	5·0

In the filtrate from a properly-worked coke-breeze filter, or "bacteria bed," the suspended matters are reduced to a mere trace, which can be best determined by the micro-filter.

The following are the results of a series of daily determinations of the quantity of suspended matters in the water of the river Thames from Teddington to the Nore during 1893-4, made at the same time as the "oxygen absorbed determination." It must be noted, however, that in most of

these cases the suspended matter consisted largely of loam and sand:—

Table LXXII.

Total Matters in Suspension—Monthly Averages.

Locality.	HIGH WATER.								
	1893.						1894.		
	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Teddington	·03	traces	traces	traces	traces	3·11	2·28	1·17	1·28
Kew Bridge	5·22	4·67	6·66	5·58	5·59	3·56	2·86	2·65	1·90
H'smith Bridge..	3·59	2·64	3·32	7·04	6·35	9·52	6·00	4·84	2·88
Battersea Bridge	3·61	2·49	4·01	3·92	6·76	8·29	10·55	11·71	9·38
London Bridge..	9·50	24·62	19·21	26·21	18·59	16·80	24·46	23·53	16·55
Greenwich.....	5·79	10·91	8·46	9·88	11·56	5·79	13·30	16·27	5·79
Blackwall	5·68	6·08	5·27	4·25	5·56	5·54	9·54	9·34	4·46
Woolwich	3·68	5·08	4·30	4·33	6·05	7·58	9·79	16·99	6·91
Barking	2·07	2·67	2·86	2·17	2·65	2·23	5·42	7·30	5·46
Crossness	2·25	2·37	2·90	2·42	2·38	3·86	4·37	3·65	2·97
Erith	2·23	2·41	2·92	2·56	3·30	3·74	5·61	5·99	5·20
Greenhithe	3·88	2·27	3·31	3·09	6·46	7·40	9·19	7·23	8·70
Gravesend	5·98	6·75	9·84	9·53	15·16	24·71	24·71	18·73	10·43
Mucking Light..	3·54	2·15	2·10	2·68	3·79	6·28	7·01	7·02	4·80
Nore Lightship..	3·09	2·02	1·98	3·61	6·10	6·25	5·80	5·18	3·05

Quantities are expressed in grains per gallon.

Table LXXIII.

Locality.	LOW WATER.								
	1893.						1894.		
	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Teddington						—	—	—	—
Kew Bridge	1·20	1·11	1·38	·96	·60	1·99	3·42	3·26	2·04
H'smith Bridge..	2·97	3·37	3·70	2·60	1·92	2·13	3·10	2·85	2·26
Battersea Bridge	6·85	7·25	12·59	10·21	7·64	2·95	4·41	3·81	4·24
London Bridge..	13·59	14·66	22·74	27·75	27·65	12·07	6·92	5·67	3·09
Greenwich.....	7·89	25·94	35·12	21·74	27·22	22·43	17·47	14·79	11·83
Blackwall	4·86	9·78	13·79	7·18	10·50	12·19	11·79	10·73	8·01
Woolwich	4·68	6·56	7·21	10·05	5·48	5·28	9·43	11·66	5·54
Barking	3·44	7·60	7·25	8·59	5·65	3·94	8·39	16·57	12·02
Crossness	7·89	8·88	14·42	6·88	10·10	8·35	17·81	18·44	6·96
Erith	3·29	4·00	4·18	3·75	4·99	3·36	4·09	6·57	3·83
Greenhithe	5·19	3·27	5·22	2·69	5·42	7·73	7·93	5·95	9·53
Gravesend	4·91	5·28	7·41	6·27	9·87	9·53	18·98	12·89	8·08
Mucking Light..	7·89	18·57	9·27	10·80	18·73	31·75	11·23	15·62	8·25
Nore Lightship..	3·15	2·49	3·71	4·40	10·93	8·29	4·81	5·33	5·20

Quantities are expressed in grains per gallon.

For comparison with the above, the following results of the filtered water supplied to London will be interesting :—

Table LXXIV.

Average Quantity of Suspended Matter during 1895.

Source of water.	Grains per gallon. Mineral.	Organic.	Total.
Intake water, river Thames, Sunbury....	0·4181 ..	0·1179 ..	0·5360
Kent Company's supply.....	0·0007 ..	0·0004 ..	0·0011
New River Company's supply	0·0006 ..	0·0005 ..	0·0011
East London Company's supply	0·0015 ..	0·0012 ..	0·0027
West Middlesex Company's supply.....	0·0005 ..	0·0005 ..	0·0010
Grand Junction Company's supply	0·0010 ..	0·0013 ..	0·0023
Chelsea Company's supply.....	0·0014 ..	0·0013 ..	0·0027
Lambeth Company's supply.....	0·0018 ..	0·0015 ..	0·0033
Southwark Company's supply	0·0031 ..	0·0025 ..	0·0056

The following table shows the comparison of the quantity of suspended matters in the above waters, during the latter six months of that year, as determined by the micro-filter method and the gravimetric process :—

Table LXXV.

Company.	JUNE.		JULY.		AUGUST.		SEPTEMBER.		OCTOBER.		NOVEMBER.		Average.
	Mm. in micro-filter per litre of water.	Grains per gallon.	Mm. in micro-filter per litre of water.	Grains per gallon.	Mm. in micro-filter per litre of water.	Grains per gallon.	Mm. in micro-filter per litre of water.	Grains per gallon.	Mm. in micro-filter per litre of water.	Grains per gallon.	Mm. in micro-filter per litre of water.	Grains per gallon.	
													Mm. grains. Mm. grains.
Kent	0·0	0·0006	0·2	0·0006	0·1	—	0·8	—	0·4	0·0008	0·3	0·0007	0·3 =0·0007, or 1=0·0023
New River.....	0·0	0·0010	0·2	0·0012	0·2	0·0011	0·8	0·0013	0·4	0·0009	0·3	0·0010	0·3 =0·0010, or 1=0·0033
West Middlesex..	0·1	0·0012	0·2	0·0014	0·2	0·0008	0·7	0·0007	0·4	0·0007	0·4	0·0009	0·4 =0·0009, or 1=0·0022
Chelsea	0·4	0·0038	0·5	0·0020	0·3	0·0013	0·4	0·0024	0·4	0·0016	0·4	0·0013	0·4 =0·0021, or 1=0·0052
East London	0·4	0·0019	0·3	0·0030	0·2	0·0020	1·1	0·0027	1·1	0·0040	0·5	0·0015	0·6 =0·0025, or 1=0·0042
Grand Junction ..	0·4	—	0·2	0·0037	0·3	0·0031	0·7	0·0018	0·4	0·0013	0·3	0·0016	0·4 =0·0023, or 1=0·0057
Lambeth.....	0·3	0·0026	0·2	0·0020	0·1	0·0018	0·8	0·0023	0·4	0·0026	0·4	0·0015	0·4 =0·0021, or 1=0·0052
Southwark.....	0·7	0·0098	0·7	0·0057	0·4	0·0031	1·1	0·0022	0·9	0·0013	0·6	0·0011	0·7 =0·0039, or 1=0·0056
Average	0·3	0·0010	0·3	0·0024	0 2	0·0019	0·8	0·0019	0·6	0·0016	0·4	0·0011	0·44=0·0019, or 1=0·0042

—	SEPTEMBER.		OCTOBER.		NOVEMBER.		DECEMBER.		Average.
	Mm. in micro-filter per litre of water.	Grains per gallon.	Mm. in micro-filter per litre of water.	Grains per gallon.	Mm. in micro-filter per litre of water.	Grains per gallon.	Mm. in micro-filter per litre of water.	Grains per gallon.	
									Mm. grains. Mm. grains.
River Thames at Sunbury.....	1·8	0·1718	4·8	0·2020	33·7	1·1775	7·8	1·4870	12·0=0·7569, or 1=0·0633

Nitrates.—Usually sewage, unless perfectly fresh, contains no nitrates, but this is a case by no means without exception, although the quantity present in a given volume must always be less than that present in the originally clean water supplied to the town. It is obvious that the presence or otherwise of nitrates entirely depends upon the time the sewage matters have been in contact with the water used for flushing. If a sufficient interval has not elapsed, the nitrates originally present in the water supplied will not be reduced by the action of the de-nitrifying organisms, and therefore they will be found in the sewage if looked for at once.

In the course of the experiments at Barking the following results were obtained:—

Table LXXVI.

Average Quantity of Nitrogen as Nitrates in the Barking Creek Effluents.

1894.	Effluent from precipitating tanks.	Filtrate.
	Grains per gallon.	
April 7th to June 9th	0·128	0·238
August 3rd to Nov. 9th....	0·022	0·141
Nov. 16th to March 2nd ..	0·396	0·699
April 8th to April 20th	0·143	0·770

As in a very large number of cases there were no nitrates at all in the raw sewage, oxidised nitrogen in the effluent shows the satisfactory progress of the work of the bacteria in the filter bed in oxidising the nitrogenous organic matter.

The great point, however, to be observed in connection with sewage treatment is that if the filtrate or effluent is well charged with nitrates, there is not much fear of the process of purification coming to a sudden stop. But should these decrease and disappear, there is danger of putrefaction; and in the case of a bacteria bed effluent, rest must be at once given to the bed.

For comparison, the following tables of nitrates in various waters, in addition to those already given, will be useful:—

TABLE LXXVII.

River Thames.

		Nitrogen, as Nitrates and Nitrites. Grains per Gallon.
Sunbury.	Average—Summer	0·206
,,	,, Winter	0·258

London Water Supply.

Kent Company		0·401
Filtered River Supplies.	Average—Summer	0·128
,, ,, ,,	,, Winter	0·258

Various Waters.

Welsh Rivers	0·022
Chalk well	0·370
Deep well	0·540
Well, 60 ft. deep	1·010
Spring	0·028
Polluted well	1·880
Ditto	4·360
Shallow well, 14 ft. deep	1·150

In connection with the question of suspended matters in water, &c., the following series of analyses will be of interest for reference. (Table LXXVIII.) These were prepared for and submitted to the Royal Commission on Metropolitan Sewage Discharge in 1883. Further determinations of the percentage of nitrogen in the organic matter held in suspension in water will be found on p. 264.

Bacteriological Examination.—The presence of the bacillus coli communis in water was formerly held to indicate direct sewage contamination. It is now known that this organism may be derived from many sources, such as the excreta from horses and other animals, so that its presence in waters collected from gathering grounds is practically universal, and unless

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they are present in unduly large numbers accompanied by other bacteria, such as the bacillus euteritides sporogenes and streptococci, little notice need be taken of them, otherwise no water supply of this nature could be admitted as sufficiently pure for potable purposes. In the case of waters from deep wells it is held by some, however, that the presence of even one or two bacilli coli communis indicates so suspicious a condition of affairs, that such waters should be either filtered or subjected to treatment by Clark's softening process, in order to afford a further defence against sudden contamination, should such occur, by reason of the breakdown of fissures, &c.

In this connection bacteriology has been in a transition stage. At first, large numbers of bacteria of any kind were held to indicate pollution. Then it was assumed that the presence of bacillus coli communis in any numbers indicated danger. Next it was admitted that these might be present in limited numbers in surface waters, unless they were accompanied by others of a suspicious character. Further experience has shown that during periods of heavy rainfall, when the water level in the ground rises and the water has consequently a less degree of filtration through the ground before it reaches the well, the bacillus coli communis and its allied forms will occasionally be present. The fact that, under these circumstances, the total quantity of chlorine in the water will frequently be diminished, clearly indicates that the source of pollution, if it can be properly so called, cannot be due to ordinary sewage contamination. In all these cases it is most important that the history of the water should be clearly ascertained, as it is evidently improper to impute serious contamination to a water when the variations are due to ordinary causes and in no way to human excremental pollution.

Now and then one meets with reports in which some new form of bacterium is mentioned, with the remark that "in the

present state of our knowledge the importance to be attached to the presence of this organism is uncertain." Such sensationalism is to be most strongly deprecated. Bacteriology has done yeoman service, and requires no such bolstering as this to frighten public authorities into spending money on further bacteriological examinations, which, unless controlled by chemical examinations and a complete knowledge of the facts, are apt, as in the past, to create needless apprehension.

CHAPTER XX.

VENTILATION AND DEODORISATION OF SEWERS.

THE various means for preventing as far as possible the formation of offensive gases in sewers, and for disposing of such gases when formed by ventilating the sewers, have received the earnest attention of various authorities for many years, and have necessarily been under the constant investigation of persons interested in the sanitary conditions of towns. The mere enumeration of all the schemes suggested and the experiments tried would occupy much space to no advantage. Prior to the year 1850 the sewers of London were almost wholly ventilated by means of gully gratings in the gutters at the edge of the foot-pavements. These gratings were at times mediums of great offence to foot passengers and to residents in the houses adjacent, and it became necessary to trap them. In the year 1849, Mr. Henry Austin, the consulting engineer to the Metropolitan Commissioners of Sewers, recommended that the trappings should only be proceeded with as other means of ventilation were provided, otherwise the sewers would be rendered dangerous, and Sir Joseph (then Mr.) Bazalgette was directed by the Commissioners to make a series of experiments as to ventilating sewers by means of shafts leading from the crown of the sewers to gratings in the centre of the road. These experi-

ments showed that a reduction of the nuisance followed from ventilating through shafts and trapping the side gullies, and consequently that method of ventilating the sewers of the metropolis was gradually adopted.

In view of the considerable improvements brought about by this alteration, the system has now become almost universal. The change, however, did not reduce the quantity, or materially affect the nature of the gases rising from the sewers in the streets. In their diluted form the sewer emanations were far less perceptible to pedestrians and residents than formerly, and were less liable to be injurious to health; but as they were still at times a nuisance, it appeared desirable either to dispose of them in some other way or to render them inoffensive before their discharge into the streets. Of the numerous schemes for effecting this object which have been suggested from time to time since 1850, by far the greater number have been found on careful examination to be either wholly impracticable, or quite unsuitable for a large system of sewers.

Sewer gases are evolved during the decomposition of substances passing through or deposited in the sewers; and this decomposition takes place to a greater extent when the contents of the sewer are in a stagnant or nearly stagnant condition. A much less quantity of gas is evolved when the temperature is low and the sewage is diluted and flowing through the sewer freely. It is therefore of the first importance that sewers should be constructed with as good a fall as practicable, and should have a copious flow of water through them. The discharge into the sewers of specially offensive trade refuse or filth also gives rise to offensive gases in the sewers. Although to cause such a discharge is an offence, it is unfortunately done to a great extent, and the difficulty of detecting such practices is considerable. Another source of special nuisance arises from the discharge, from

manufactories and other places, of steam or hot water into sewers. In the metropolis this is now a legal offence.

The want of sufficient water carriage is one of the principal causes of nuisance. However offensive sewage may be when stagnant, it gives off little offensive effluvium when it is fresh and largely diluted with water flowing at a fair velocity. The extent to which it is diluted determines the degree of the offensiveness of the sewage itself, and swiftness of flow removes it before material decomposition sets in. Ample flushing is therefore the best remedy.

The late Sir Joseph Bazalgette reported in 1866 as follows :—"The most efficacious and most universally applicable mode of preventing the escape of noxious gas is so to construct the sewers that a continuous flow shall be kept up in them, and to provide them with a sufficiently copious supply of water, that decomposing matters within them shall be diluted and instantaneously removed, and not allowed to settle or ferment in the sewers. Much improvement has already been effected in the ventilation of the London sewers by the abolition of the tide-locked and stagnant sewers, and much more may yet be accomplished by the introduction of a more copious supply of water."

The practice of flushing varies very considerably, both as to times and methods. In some cases the smaller sewers are usually flushed with water drawn from the stand pipes on the water companies' mains, and discharged into the sewers through hose, or by means of water vans. In some cases, however, the water is not sent at once into the sewers, but is accumulated in the shafts or side entrances, and is then suddenly discharged, the sewers being effectually scoured for some distance. A still larger head of water is sometimes obtained by the use of storage tanks, from which the water is suddenly discharged, either by hand or automatically, and in many cases this is most successful.

The escape of sewer gas is at times very perceptible at the upper end of branch sewers, and it is therefore necessary that provision should be made for flushing from the commencement or "dead ends" of local sewers, as in the absence of such flushing those sewers are in dry seasons specially liable to be sources of nuisance.

In order to prevent the escape of gases from the sewers during flushing, provision must be made for ventilation, otherwise the escaping gases would be forced through the traps into houses at every sudden discharge into the sewers, and the health of the inhabitants of every household imperilled.

The conditions governing the ventilation of sewers have been a matter of considerable debate. Many people are of opinion that temperature is the only factor. On the other hand, the late Mr. Santo Crimp, who paid considerable attention to the question, was strongly of opinion that the direction of the wind is the chief controlling factor, and he gave many instances in support of his contention. The advocates of the temperature theory contend that as the temperature of the air of the sewers is lower than that of the external atmosphere, when no other influence is at work the colder atmosphere of the sewer, being heavier than the external air, remains in the sewers; but when the outer air becomes colder, and consequently heavier than the sewer air, it presses down through some of the openings of the sewer and drives out the warmer and lighter air through other openings, as for instance, in the cool of the evening in hot dry seasons, at which times the nuisance from ventilators is stated to be probably at its worst.

During the autumn and winter months the average temperature of the air of sewers is warmer than the external atmosphere by about 7 deg. Fahr. In spring, the temperature is about equal; and in summer, the external day temperature averages

over 3 deg. warmer than that in the sewers. At night the temperature of sewers, at all times of the year, is usually higher than the temperature of the external air. It will therefore be seen that throughout the greater part of the year, the law by which the heavier external air forces out by its greater weight the warmer air of the sewers is in operation; and, if proper facilities are given, such ventilation of the sewers ensues. The temperature of the air of sewers is, however, affected locally by hot water and other liquids poured into them. Every such discharge at once raises the temperature of the air in its vicinity, and the sudden expansion which follows causes air to escape up the nearest opening.

In like manner, every increase in the quantity of sewage by a discharge from a drain into the sewer expels air from the sewers, and assists ventilation. In fact, every rise or fall in the level of the sewage either expels air from or draws it into the sewer; and, as the level of the sewage is constantly changing, this materially assists ventilation.

In a system of sewers ventilation should be as constant as possible in its operation; it should effect the greatest possible change in the air of the sewer with the least amount of nuisance to the public; and it should do this automatically and economically. That no system of ventilation has been found which is entirely successful is probably due to the fact that the complexity of the conditions renders a perfect system very difficult of attainment. Of the numerous schemes that have been proposed, by far the greater number deal with one section of the subject only, and do not take into account all the practical considerations affecting sewers.

As an instance of this may be mentioned the proposal frequently made that the principle adopted in the ventilation of mines should be applied to sewers. That system, as applied in mines, has proved very successful indeed. Fresh

air is drawn through one downcast shaft, and travels through the various galleries and cuttings to an upcast shaft, through which it passes from the mine. The force which moves the air is either a fire in the upcast shaft or a fan. It has been assumed that such a method cannot be applied to a system of sewers, because instead of the air entering at one point and being quickly distributed throughout the system, it would be drawn into the sewers only through the drain openings nearest to the fan or exhaust shaft, and the remainder of the sewers would receive no benefit. Formerly, no doubt, this was so, but recent improvements in electrically-driven fans have shown that the difficulty is not insurmountable. For instance, the Aldous system, tested by me at West Ham, entirely withdrew the impure atmosphere from a series of sewers having a combined length of 6,200 feet, varying in size from a 3 ft. × 2 ft. culvert to a 12 in. tube. The following are the particulars of the experiment.

My observations were particularly directed to two points, viz. :—

(*a*) The effect of the process in removing the existing air in the group of sewers selected for the trial.

(*b*) The rapidity with which this removal took place.

With these objects in view, I charged a group of sewers at six different points distributed fairly over the area under examination with sulphurous acid gas, and watched its disappearance from these points and subsequent re-appearance at the outlet from the fan exhaust which was working at the end of the allotted district, the site having been selected in order that the system might be tried under the most stringent conditions.

On December 19th, 1901, the gaseous acid was discharged into the sewers as follows:—

Sarah Street, dead end of sewer,	794 ft.	from the fan ..	11.40 a.m.
Charlotte Street ,, ,,	750	,, ,, ..	11.55 ,,
Hack Road, on outer boundary	1,021	,, ,, ..	12.5 p.m.
Catherine Street, highest point	1,232	,, ,, ..	12.15 ,,
Queen's Road, main sewer	1,091	,, ,, ..	12.25 ,,
Bengeo Street, dead end	1,241	,, ,, ..	12.35 ,,
The fan in Rivett Street, Victoria Dock Road, was started at			12.35 ,,

A few minutes before starting the fan, on examining the lamp-holes in Queen's Road at points further away from the fan than that at which the sulphurous acid had been introduced, the acid was distinctly detected, thus showing that the acid gas had travelled up the sewer away from the fan in the few minutes' interval which elapsed before the fan was started.

After the fan had been at work about twenty minutes, the acid was present in the exhaust pipe in considerable quantities, but ceased to appear about 2 p.m., or an hour and a half after the last quantity was put in at the dead end in Bengeo Street, 1,241 feet away.

The various man-holes were inspected whilst the fan was at work, and in every case there was a distinct down-draught into the sewer, this being clearly observable even in the Queen's Road sewer beyond Lansdowne Road, a considerable distance outside the area selected for the trial.

Between 4.5 and 4.15 p.m. a further quantity of sulphurous acid was discharged into a man-hole in Catherine Street, 1,232 feet from the fan—and was detected at the exhaust pipe at 4.30 p.m., but ceased to be detectable at 4.55 p.m., thus clearly demonstrating that the air of the sewer on the extreme boundary of the series was changed, notwithstanding the many intermediate ventilators and man-holes, within twenty-five minutes, although the fan had first

to set up an exhaust in a 3 ft. × 2 ft. culvert before it could affect the local sewers in question.

On the 31st December, 1901, further trials were made with sulphurous acid, which was introduced into the sewer through a lamp-hole in Queen's Road, near Lansdowne Road, at 4.45 p.m., the fan being at work. The acid appeared at the fan at 5.10 p.m., or in twenty-five minutes after it was placed in the sewer, 1,469 feet distant. At 5.45 p.m. it was no longer detected at the fan, showing that the atmosphere was not only changed in the sewer at Lansdowne Road, quite outside the district selected for trial, but that the impure atmosphere had been entirely withdrawn from the sewers under experiment in less than an hour.

In addition to the foregoing, further tests were made to ascertain the effect of the system on the quantity of carbonic acid present in the atmosphere of the sewer before and after the fan had been at work.

These were made on the 31st December last, with the following results :—

Carbonic acid present in the sewer air, stated in parts per 10,000.

		Before the fan started.
Sarah Street	11 a.m.	7·6
Hack Road	11.15 a.m.	4·7
Queen's Road	11.30 a.m.	7·2
		After the fan had been working 3 hours.
Sarah Street	3.15 p.m.	4·9
Hack Road	3.25 p.m.	4·5
Queen's Road	3.30 p.m.	4·9

From these results it is evident that the impure atmosphere in the sewer before the fan started must have been removed and its place supplied by atmosphere from the streets.

With reference to the Hack Road results, it was observed that during the period of the tests, the cover of a man-hole in that road had been removed by some men engaged in work

on the sewers, thus accounting for the lower quantity of carbonic acid found before the fan was at work.

Having regard to the definite and repeated results obtained in the above most carefully conducted experiments, there can be no doubt as to the practical efficiency of the system, which, although working under designedly difficult circumstances with regard to the position of the fan, in order to give a thorough trial, produced a continued and effectual replacement of the foul sewer air by a fresh supply, over a total length of about 6,200 feet of sewers, varying in size from a 3 ft. × 2 ft. culvert to a 12 in. tube.

The rate at which the fan withdrew air from the sewer was 530 feet linear per minute from the 9 in. diameter pipe, showing, during a three hours' run, an exhaust from the sewer equal to 42,167 cubic feet.

The methods of ventilating sewers that experience has shown to be practicable are:—

(*a*) By surface ventilation: that is to say, by shafts leading from the crown of the sewers to the centre of the road, covered at the road level by open gratings.
(*b*) By large and small separate shafts and factory chimneys, in which fire or other heat is the suction power.
(*c*) By pipes or shafts without heat.
(*d*) By air currents mechanically induced by fans.

The objection to surface ventilators is rather on account of the gases escaping from them being more directly in evidence than to their being more dangerous to health than any other method of ventilation. Although the improvement effected by removing the points at which sewer gas escapes from the side of the footpaths to the centre of the road is very great, both in reducing offence and in minimising danger to health, there can be no doubt that at times the system is, as at present carried out, a serious cause of nuisance.

The question of deodorising sewer gases before their escape through the ventilating shafts or surface gratings has received much attention from drainage authorities and others interested in the subject. If, without materially interfering with the ventilation of the sewers, the gases could be readily, economically, and effectually deodorised before reaching the exterior air, one of the greatest difficulties in connection with the subject would be solved. This object has been attempted in various ways, either by means of fire, by the agency of chemical substances, or, more generally, by means of charcoal. General experience, however, has shown that the method of filtering the gases through cages containing charcoal is a failure in consequence of the charcoal becoming wet or clogged, and thereby being rendered useless. This system appears to be generally abandoned.

If it be desired to adopt a chemical method of deodorising the sewage and thereby prevent noxious emanations, this can only be done in one way, viz., by adding a solution of permanganate of potash, or soda, directly to the sewage, and so keeping it in a comparatively fresh condition until its arrival at the sewage works. The result of experience has been to show most clearly that the quantity of permanganate required to destroy existing foul odours, and to stay the production of others, is exceedingly small, being only from one to two grains per gallon. To obtain the maximum effect with the minimum expenditure it is advisable that the points of application should be multiplied to the greatest extent practicable; and householders should be urged to systematically use this and similar oxidising disinfectants freely. Various expedients have been suggested for the purpose of accomplishing this object. One very simple arrangement was to fill a porous pot, such as used for electric batteries, with the crystals of permanganate of potash, and suspend this in the special cistern supplying the lavatory, &c., when a slow

solvent action took place by osmosis through the pores of the vessel, and the water in the cistern was thus kept charged with dissolved permanganate. Such a system, if universally adopted, would be of the greatest possible benefit.

Some time back Mr. Harris Reeves took up the idea suggested by the use of manganate of soda and sulphuric acid for the temporary deodorisation of the London sewage pending the opening of the outfall precipitation works, and constructed a convenient arrangement of earthenware, by means of which a solution of manganate of soda was constantly prepared, and to this was added, as it flowed over a porcelain capsule, strong sulphuric acid, the action of which not only converted the cheap manganate of soda into the permanganate, but by the heat set up by the action of the acid evolved *vapours* of permanganic acid, probably one of the most powerful deodorants we have.

This system appears to have been tried at various places with marked success for the purpose of dealing with special ventilators which have been found to be a nuisance. In one case nine man-holes were so treated at a first cost of 112*l.*, and an annual working expense for manganate of soda and sulphuric acid of 20*l.*, the labour being performed by the ordinary staff without extra cost. Equally satisfactory results appear to have been obtained elsewhere, but it is evident that the cost of this system is against its general adoption for all man-holes, however suitable it may be for special cases.

As the result of most careful inquiry into the whole question of the cleansing and ventilation of sewers by the Special Purposes and Sanitary Committee of the late Metropolitan Board of Works, that Committee reported in January, 1886, the following conclusions and recommendations on the subject:—

(1.) That old, defective, disused, or partially disused sewers

should be disconnected from the present sewerage system, cleansed and filled up; and that, where necessary, pipes or other proper sewers should be substituted.

(2.) That stringent measures be taken for preventing road sweepings passing into sewers, and for preventing the discharge into sewers from manufactories and other places of improper substances, such as chemical refuse or trade filth, or of hot water or steam, so as to be the cause of nuisance.

(3.) That the most important requirement for keeping sewers in satisfactory condition is a supply of water sufficient in quantity to carry the sewage in suspension through the sewers.

(4.) That whenever the supply of water is insufficient for cleansing the sewers, effectual provision for cleansing such sewers should be adopted by flushing or other means.

(5.) That one of the most effectual methods of flushing would be by means of water simultaneously discharged into house drains, and such a simultaneous discharge would flush branch sewers, then local sewers, and finally main sewers; that such method of flushing can be effectually carried out by householders flushing their house drains periodically and simultaneously at stated times; that a great number of householders would probably be willing to co-operate with the Authorities in improving the condition of the sewers in their district in this way; and that it is desirable that the several Vestries and District Boards should intimate upon what days and at what hours householders should flush their drains.

(6.) That provision near the heads of branch sewers for flushing such sewers from their commencement is to be desired.

(7.) That the practice of flushing the courts, alleys, small streets, &c., in poor districts in summer is to be highly

recommended as a desirable method of flushing sewers and improving the sanitary condition of the districts.

(8.) That next to effectual cleansing one of the most important safeguards against nuisance and danger to health from sewers is the dilution of the gases therein by a constant and plentiful supply of fresh air to the sewers by means of effective ventilation.

(9.) That the ventilation of sewers in the metropolis by means of ventilating shafts leading to gratings in the centre of roadways has been the cause of complaint, owing to the imperfect manner in which the system has been carried out, the ventilators being deficient both in size and numbers.

(10.) That the surface ventilators to the recently-constructed sewers have ordinarily been placed at a distance of from fifty to sixty yards apart, with air openings in the gratings equal to sixty square inches; and that the number and size of many of the ventilators and the sewers in the metropolis should be increased.

(11.) That the amount of ventilation afforded by large special ventilating shafts is in no way commensurate with their cost, and that the adoption of such shafts, with or without fire heat, or the connection of the sewers with factory shafts, can only be adopted in very exceptional circumstances. Where shafts with fire are used, the sewer gases should be allowed to pass into such shafts over as well as through the fires, otherwise the amount of ventilation afforded will be very limited.

(12.) That pipe ventilators of large section, and constructed with bends, and without angles, can be used with great advantage in addition to, and not in substitution for, surface ventilators, wherever the consent of owners and occupiers can be obtained to such ventilators being affixed.

(13.) That your Committee are of opinion that the ventilation of the sewers of the metropolis may be improved by

altering the construction of many of the surface ventilators as previously recommended, and by carrying up large pipe ventilators at convenient points wherever practicable.

(14.) That the use of charcoal or of other appliances for deodorising gases in sewer ventilators is undesirable, as such appliances do much harm by obstructing ventilation, are costly and troublesome, and are quite unsuitable for general use over a large sewerage system.

(15.) That during the cold and wet seasons the arrangements suggested in this report for providing ventilation will be sufficient, as putrefaction proceeds slowly at low temperatures; and when the sewage is diluted with large volumes of fresh water, that the foul matters pass from the sewers before material quantities of offensive gases are generated.

(16.) That during dry and hot weather the foregoing recommendations respecting the flushing and cleansing be carried out as far as practicable, especially in sewers having only a small flow of water.

(17.) That in addition to these precautions, a system of deodorisation during the summer be arranged for the main sewers on the plan adopted by the Board during the past summer (by permanganate of soda); and that Local Boards be requested to adopt a similar system with local sewers, and to use all their influence to induce householders to employ in their house-drains suitable deodorising agents during periods of high temperature and drought.

(18.) That manufacturers and others discharging refuse into the sewers be compelled to so treat their waste (by such process as they may deem fit, but to the Board's satisfaction) that it shall have no greater *deoxidising* powers than the average household sewage.

In the course of a series of experiments on the micro-organisms contained in sewer air made for the Main Drainage

Committee of the London County Council by Mr. J. Parry Laws, F.I.C., that gentleman came to the conclusion that they were not only less in number than the micro-organisms in fresh air in the vicinity at the same time, but that they were also apparently related to and derived from those of fresh air rather than from the sewage; and further, that no evidence was forthcoming that sewage was able to give off micro-organisms to the air in contact with it. Inasmuch as these conclusions were not in harmony with generally-accepted views—although not published for the first time, as was shown by Drs. Carnelly and Haldane a few years previously—it became of great importance to gain corroborative evidence upon the point by a study of the organisms existing in sewage, and to this end further investigations were carried out at the instance of the Committee by Mr. Parry Laws in conjunction with Dr. F. W. Andrews in 1894.

The conclusions arrived at by these gentlemen, so far as related to the first part of their investigations, were as follows:—

CONCLUSIONS OF MESSRS. LAWS AND ANDREWS.

"If we now proceed to contrast the micro-organisms which we have found present in London sewage, as above described, with those found in the air of London sewers, and described in a previous report, certain striking differences become at once apparent. The most striking is the absence of moulds from sewage. Out of the many thousand colonies which arose in the numerous plates which were made, moulds occurred only seven times, and of those seven moulds one, and one only, was allied to the common species existing in sewer air. This result coincides with that obtained by Jordan in the sewage of Lawrence, Mass. 'Moulds,' he says, 'are found rarely in the sewage and effluents.' Further, the same striking result was obtained by Mr. Dibdin in a series

of experiments he made on the number of micro-organisms in Barking sewage. In sewer air, on the contrary, moulds were found to be a predominating feature, forming on an average no less than 64·33 per cent. of the total colonies. The proportion, however, varies according to season; in winter it may be as low as 13·33 per cent., while in the summer months it may rise as high as 82·6 per cent. of the total. It is right, however, to point out that in our sewage experiments, agar-agar, which is a less favourable medium than gelatin for the growth of moulds, was employed, whereas in the estimation of the organisms present in sewer air gelatin was used. This, however, does not materially affect our results, since most moulds grow well on agar-agar at a temperature of 22 deg. Cent. Jordan and Dibdin, moreover, employed gelatin plates only.

"Bacillus coli communis was found, with one exception, in each sample of sewage we examined, and varied in numbers from 20,000 to 200,000 per cubic centimetre. In addition we isolated in every case many bacilli which, although indistinguishable in cultural features from bacillus coli communis, nevertheless gave only one, or at most two, of the three characteristic chemical reactions. These bacilli in most instances far outnumbered the true bacillus coli communis. Nevertheless, neither B. coli communis nor any of its close allies were ever found in sewer air. Furthermore, we have obtained enormous numbers of sarcina, amounting in one case to over 300,000 per cubic centimetre, yet we have not found one single colony of sarcina lutea, which is so common in sewer air and fresh air.

"The flora of sewage naturally embraces a very large number of different species of bacteria, but when we consider the enormous number of micro-organisms per cubic centimetre and the extreme degree of dilution that it is necessary to employ in making cultivations, it will be evident that we

have probably isolated only those species which are present in comparatively large numbers. The following organisms are those which we have found to be present in numbers varying from 200,000 to 2,500,000 per cubic centimetre—bacillus fluorescens stercoralis, bacillus albus putidus, bacillus fluorescens liquefaciens, bacillus cloacæ fluorescens, bacillus mycoides, proteus cloacinus, proteus Zenkeri, a streptococcus coagulating milk, staphylococcus pyogenes citreus, sarcina flava and its allies, and diplococcus albicans tardissimus. Other bacilli, which rapidly liquefy gelatin and produce a green fluorescence, were found in numbers varying from 10,000 to 200,000 per cubic centimetre.

"A further difference between the bacteria of sewer air and those of sewage lies in the relative proportions of micrococci and bacilli. The bacteria of sewer air were found to consist mainly of micrococci, bacilli forming but a small proportion of the total species found. The bacilli found were B. subtilis, B. aureus, B. arborescens, B. helvolus, B. nigrescens, and B. acidi lactici. In sewage itself, however, there can be no doubt that bacilli preponderate over micrococci, probably in actual numbers, certainly in the numbers of species present. The large majority of those species which we have been obliged to pass over were bacilli. This was less noticeable in the fresh sewage taken from St. Bartholomew's Hospital, where the large number of streptococcus colonies materially altered the ratio between the bacilli and micrococci; in the sewage taken from Snow Hill and Barking the bacilli showed a distinct numerical preponderance. This result again is in harmony with that obtained by other observers, indeed the results we have obtained show a somewhat smaller preponderance of bacilli over cocci than has been recorded by others. Jordan states that the comparative absence of micrococci from sewage is a striking and highly remarkable circumstance. In any case, the facts again come

out in striking confirmation of the view that the organisms present in sewer air are not derived to any essential extent from the sewage, or they would show to some degree the same relative ratio of micrococci to bacilli. The argument receives also important confirmation from other considerations. A large proportion of the bacteria of sewage have the property of very rapidly liquefying the nutrient gelatin used as a cultural medium—so large a proportion, indeed, as to make gelatin an impossible medium to employ in estimating their numbers. In sewer air, on the contrary, organisms rapidly liquefying gelatin were found to be practically absent, a fact impossible to explain on the assumption that sewer air is able to take up bacteria from sewage.

"Again, the number of micro-organisms existing in sewer air appears to be entirely dependent upon the number of micro-organisms existing in the fresh air at the same time and in the same vicinity. With the advance of the colder weather, and consequent rapid decrease in the number of micro-organisms in fresh air, we find a corresponding decrease in the number of the micro-organisms of sewer air, although the temperature of the sewer air and sewage suffer but a comparatively slight variation.

"If the organisms existing in sewer air were derived from those existing in sewage, then the flora of sewer air should bear a very close resemblance to the flora of sewage. When, however, we compare the organisms which have hitherto been isolated from sewer air with those species which we have found to be *predominant* in sewage, it is at once evident that they bear no resemblance whatever to one another; indeed, we may go even further, and state that, so far as we are aware, not a single colony of any of those species which we have found predominant in sewage has been isolated from sewer air. We consider, therefore, that the study of the

sewage bacteria, on which we have been engaged, fully confirms the conclusion previously arrived at from the study of the micro-organisms of sewer air, viz., that there is no relationship between the organisms of sewer air and sewage.

"It is possible that some of the ill effects which have been erroneously ascribed to sewer air may be due to subsoil air derived from soil polluted by constant infiltration of excremental matter through a leaky drain. It is a well-recognised fact that subsoil air does at times gain access to our dwellings, either through the pressure of the wind on the surface of the ground, or from currents induced by wide differences between the exterior and interior temperatures. Under such conditions it is possible that sewage may gradually extend through a permeable soil until its outer margin becomes sufficiently dry to give off micro-organisms to the subsoil air. Whatever the danger arising from this cause may be, it would in all probability be strictly limited in its effect."

Continuing their investigations on the vitality of the typhoid bacillus in sewage, Messrs. Laws and Andrews made, amongst others, the following experiment:—

"*Experiment V.*—A tube of sewage sterilised by heat was inoculated with one drop of a fresh broth culture of B. typhosus, and incubated at 20 deg. Cent. A small quantity was removed on a platinum loop and transferred to gelatin immediately after inoculation to determine the number of colonies originally present, and the process was repeated at stated intervals. The results were as follows:—

Immediately after inoculation	225	colonies arose.
After twenty-four hours	250	,, ,,
,, sixty-eight hours	140	,, ,,
,, five days	48	,, ,,
,, seven days	13	,, ,,
,, thirteen days	0	,, ,,

"It is to be observed that the removal of so small a quantity of fluid as can be conveyed on a platinum loop is no fair test of the total absence of living bacilli from a culture, and it is quite possible that the removal of larger quantities might have shown living bacilli to be present after thirteen days. Similar, or approximately similar, amounts would nevertheless be removed by a platinum loop on each occasion, so that the experiment clearly shows that although an attempt at growth may occur during the first twenty-four hours, the typhoid bacillus gradually but surely dies out in sewage, and is quite incapable of any active growth therein.

"Sewage, therefore, even in the absence of the normal micro-organisms which it contains, is clearly an unfavourable medium for the growth of the typhoid germ, whereas the colon bacillus can grow and multiply freely in it."

After detailing further experiments on the same subject they concluded their valuable and interesting report in the following terms:—

"So far as deductions can be safely drawn from a single series of experiments, the following conclusions seem to be warranted. Bacillus typhosus seems capable of slight multiplication in sterilised sewage during the first twenty-four hours only, thenceforward it becomes gradually extinct. The presence of certain non-pathogenic organisms, commonly present in sewage, appears to affect its extinction. Of the four organisms which we tested, B. fluorescens stercoralis alone seems to have any marked effect upon the vitality of B. typhosus, and this effect is practically absent when other organisms are present at the same time. The mixture of the four non-pathogenic bacteria had no effect in hastening the extinction of B. typhosus; indeed, the reverse appears to have been the case.

"These preliminary experiments are necessarily very in-

complete, and afford only an indication of the probable fate of typhoid bacilli which gain access in a living condition to sewage. It seems, however, clear that sewage does not form a medium in which much, if any, growth is possible for them under natural conditions, and their death is probably only a matter of a few days, or at most one or two weeks. But this degree of resistance may, nevertheless, be sufficient to allow of their being carried in sewage to remote distances and of their being able to produce disastrous results should they gain access to any water supply. As our knowledge accumulates, it becomes more and more evident that water supply, and, as an incidental result, our milk supply, constitute the chief channels of infection by which typhoid fever is communicated; and this is true also of cholera, and possibly of other infectious diseases. It is therefore of the first importance to determine in an exhaustive manner how far sewage is a possible soil for the growth of these and other disease germs which admittedly gain access to it, and also to determine what precise influence their non-pathogenic companions may exert on them.

"In the conclusions to Part I. of this report we endeavoured to show that sewer air has no power of taking up bacteria from the sewage with which it is in contact. A strong argument in favour of this view is the fact that the very organisms which are most abundant in sewage are precisely those which are absent from sewer air. In the course of previous experiments on sewer air, the nature of the organisms in some 1,200 litres of sewer air was carefully determined. Not once was Bacillus coli communis or any of the predominant organisms of sewage found, though we have shown above that the former is present in sewage in numbers varying from 20,000 to 200,000 per cubic centimetre. If this be so, how infinitely improbable becomes the existence of the typhoid bacillus in the air of our sewers. That sewage is a common

medium for the dissemination of typhoid is certain; that sewage-polluted soil may give up germs to subsoil air is possible; but that the air of sewers themselves should play any part in the conveyance of typhoid fever appears to us, as the results of our investigations, in the highest degree unlikely."

CHAPTER XXI.

THE ROYAL COMMISSION ON SEWAGE DISPOSAL.

In consequence of the rapid development of the methods of treating sewage solely by the agency of bacteria and the increasing urgency of the sewage question generally, a Royal Commission was appointed on the 7th May, 1898, under the presidency of the Earl of Iddesleigh, to inquire and report:—

> I.—(1) What method or methods of treating and disposing of sewage (including any liquid from any factory or manufacturing process) may properly be adopted, consistently with due regard for the requirements of the existing law, for the protection of public health, and for the economical and efficient discharge of the duties of local authorities; and
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> (2) If more than one method may be so adopted, by what rules, in relation to the nature or volume of sewage, or the population to be served, or other varying circumstances or requirements, should the particular method of treatment and disposal to be adopted be determined; and
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> II. To make any recommendations which may be deemed desirable with reference to the treatment and disposal of sewage.

On the 12th July, 1901, the Commissioners issued an interim report, from which the following salient features are abstracted, viz.:—

> 3. We have, however, arrived at conclusions on three questions which appear, for reasons hereafter given, to be of urgent importance, and we have therefore deemed it desirable to make a preliminary report and to publish the evidence already taken.

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The three questions are :—

(1) Are some sorts of land unsuitable for the purification of sewage?

(2) Is it practicable uniformly to produce by artificial processes alone an effluent which shall not putrefy, and so create a nuisance in the stream into which it is discharged?

(3) What means should be adopted for securing the better protection of our rivers?

5. The first Sewage Commission was appointed in the year 1857. In 1865, as a result of labours extending over eight years, they reported that :—

"The right way to dispose of town sewage is to apply it continuously to land, and it is only by such application that the pollution of rivers can be avoided."

6. In 1868 a further Commission was appointed to inquire into the best means of preventing the pollution of rivers. They made several reports, the fifth and last being made in 1874.

The opinion of this Commission on the comparative merits of the three classes of processes for the treatment of sewage—viz., chemical precipitation, intermittent filtration, and broad irrigation—may be stated thus :—(1) All these processes are to a great extent successful in removing polluting organic matter in suspension. But intermittent filtration is best, broad irrigation ranks next, and the chemical precipitation processes are less efficient. (2) But for removing organic matters in solution the processes of downward intermittent filtration and broad irrigation are greatly superior to upward filtration and chemical processes.

7. The last Commission was appointed in 1882. They were directed to inquire into and report upon the system under which sewage was discharged into the Thames by the Metropolitan Board of Works, whether any evil effects resulted therefrom, and, if so, what measures could be applied for remedying or preventing the same.

In November, 1884, they issued their final report. They found that evils did exist "imperatively demanding a prompt remedy," and that by chemical precipitation a certain part of the organic matter of the sewage would be removed. They reported, however, "that the liquid so separated would not be sufficiently free from noxious matters to allow of its being discharged at the present outfalls as a permanent measure. It would require further purification, and this, according to the present state of knowledge, can only be done effectually by its application to land."

Practice of Local Government Board.

8. Since the publication of the last-mentioned report it has been the practice of the Local Government Board to require, save in exceptional cases, that "any scheme of sewage disposal, for which money is to be borrowed with their sanction, should provide for the application of the sewage or effluent to an adequate area of suitable land before its discharge into a stream." There can be no doubt, in our opinion, that the Local Government Board were bound, under the circumstances, to insist upon such a rule.

Reasons for Reconsidering Position.

9. It is now contended that in many cases, especially in the great centres of manufacturing industry, the land available is either of unsuitable quality, is available in quite inadequate area for effective filtration through the soil, or is obtainable only at a prohibitive cost, and it is suggested that sewage purification may in such cases be carried out on comparatively small areas artificially prepared. During recent years a variety of artificial processes, differing from those which were considered by the earlier Commissions, have been elaborated for treating sewage, and it is urged that satisfactory effluents can be obtained by such artificial processes.

Scope of Work of this Commission.

10. Having regard to the definite findings of previous Commissions, to the consequent practice of the Local Government Board in insisting on the provision of land for the purification of sewage, and to the fact that the artificial processes are still only in the experimental stage, and, as might be expected therefore, the evidence in regard to them is inconclusive on many points, it has appeared to us essential to subject the artificial processes to sustained examination, and also carefully to test the contention that in certain cases it is not practicable to purify sewage by land treatment.

11. At the time of the investigations of the earlier Commissions, the science of bacteriology was in its infancy, and these Commissions confined themselves almost entirely to a chemical examination of sewage effluents. Since the dates of those Commissions a large amount of exact knowledge has been gained concerning the part played by bacteria in various processes of nature and operations of man, and it became our duty to study the various questions connected with sewage disposal, not only from a chemical but from a bacterio-.

logical point of view as well. This has largely increased our labours, but we trust will also largely increase their usefulness. We have had to initiate and carry out various bacteriological investigations, and, in particular, finding that the work done by earlier Commissions in regard to land treatment was not complete enough for our purposes, we have thought it necessary to include in our work a systematic investigation, bacteriological as well as chemical, of the treatment of sewage on land of various kinds. This investigation is on the point of completion.

CONCLUSION I.

15. We doubt if any land is entirely useless, but in the case of stiff clay and peat lands the power to purify sewage seems to depend on the depth of the top soil.

There are, of course, numerous gradations in the depths of top soil which are met with in nature, and it is not easy to draw the line between lands which contain a sufficient depth to justify their use and lands which do not.

We are, however, forced to conclude that peat and stiff clay lands are generally unsuitable for the purification of sewage, that their use for this purpose is always attended with difficulty, and that where the depth of top soil is very small, say six inches or less, the area of such lands which would be required for efficient purification would in certain cases be so great as to render land treatment impracticable.

Further information with regard to this point will be available when our investigation of land treatment is completed.

QUESTION II.—*Is it practicable uniformly to produce by artificial processes alone an effluent which shall not putrefy and so create a nuisance in the stream into which it is discharged?*

16. The following general classification will serve to show the nature of the artificial processes to which we refer:—

Closed septic tank and contact beds.
Open septic tank and contact beds.
*Chemical treatment, subsidence tanks and contact beds.
Subsidence tanks and contact beds.
Contact beds alone.
Closed septic tank followed by continuous filtration.

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* The expression "subsidence tanks" is intended to denote tanks which are used in such way that little or no "septic" action is produced.

Open septic tank followed by continuous filtration.
Chemical treatment, subsidence tanks, and continuous filtration.
Subsidence tanks followed by continuous filtration.
Continuous filtration alone.

CONCLUSION II.

19. After carefully considering, however, the whole of the evidence, together with the results of our own work, we are satisfied that it is practicable to produce by artificial processes alone, either from sewage or from certain mixtures of sewage and trade refuse such, for example, as are met with at Leeds and Manchester, effluents which will not putrefy, which would be classed as good according to ordinary chemical standards, and which might be discharged into a stream without fear of creating a nuisance.

We think, therefore, that there are cases in which the Local Government Board would be justified in modifying, under proper safeguards, the present rule as regards the application of sewage to land.

No general rule as to what these safeguards should be can be laid down at present, and indeed it will, probably, always be necessary that each case should be considered on its own merits.

Bacteriological Qualities of Effluents. Sewage Effluents in Relation to Disease.

20. As we have already said, sewage effluents must, in accordance with present knowledge, be judged not only from a chemical but also from a bacteriological point of view. In order to safeguard public health, it is, in certain cases at any rate, not enough to know the chemical features of an effluent and to ascertain that it will not putrefy of itself, we must know the bacteriological features as well.

21. Several witnesses have referred to the danger of allowing pathogenic organisms to enter streams which are used for drinking purposes, and our own officers are carrying out careful prolonged investigations on this matter.

We are impressed with the great importance of the bacteriological questions which have arisen in the course of our inquiry, but we do not, at present, feel justified in putting forward any conclusions concerning them.

We may, however, even at this stage point out, that as a result of a large number of examinations of effluents from sewage farms and from artificial processes we find that while in the case of effluents from land of a kind suitable for the purification of sewage there are fewer micro-

organisms than in the effluents from most artificial processes, yet both classes of effluents usually contain large numbers of organisms, many of which appear to be of intestinal derivation, and some of which are of a kind liable, under certain circumstances at least, to give rise to disease.

We are of opinion, therefore, that such effluents must be regarded as potentially dangerous; and we are considering whether means are available and practicable for eliminating or destroying such organisms, or, at least, those giving rise to infectious diseases.

QUESTION III.—*What means should be adopted for securing the better protection of our rivers?*

22. From the evidence which we have received, from our own observation, and from information collected for us by the Local Government Board for Scotland, we are satisfied that the Rivers Pollution Prevention Act, 1876, has not resulted in the general purification of our rivers.

23. This is due largely to the reluctance of the authorities to put the Act in force, but partly also to the difficulty which a sanitary authority experiences in proving that the pollution within its district comes from the district against which, or the person against whom, action is taken. An authority wishing uniformly to enforce the Act in its own district has no security that the authorities above and below it on the stream will do the same, and it is therefore naturally disinclined to take action.

CONCLUSION III.

30. We consider it of the utmost importance that the simplest possible means should be provided for adequately protecting all our rivers; and we are further of opinion that it will be desirable, probably for some time to come, that scientific experiments should be carried on in order to ascertain all the real dangers of pollution, against which they should be protected.

In the present state of knowledge, and especially of bacteriology, it is difficult to estimate these dangers with any accuracy, and it seems quite possible that they should be either exaggerated or undervalued according to the predisposition of those who have to deal with them. An authority, guided by medical considerations, might not unnaturally be inclined to insist on a degree of purity which may ultimately prove in certain cases to be uncalled for, while another authority, with its mind fixed upon economy, might shrink from taking essential precautions.

31. It is, perhaps, scarcely for us to say what arrangements should be made; but we are of opinion that the general protection of our rivers is a matter of such grave concern as to demand the creation of a separate commission, or a new department of the Local Government Board, which shall be a Supreme Rivers Authority, dealing with matters relating to rivers and their purification, and which, when appeal is made to them, shall have power to take action in cases where the local authorities have failed to do so.

The Second Report of the Commission was dated 7th July, 1902, and formally presented, without further observation, a series of reports by their expert officers on various questions of importance, chiefly on the bacteriology of sewage and effluents, and the pollution of the River Severn in the Shrewsbury district.

The Third Report of the Commissioners was dated the 2nd March, 1903, from which the following clauses are abstracted:—

We find that sewage containing trade effluents is generally more difficult to purify than ordinary sewage, and that the following are the chief causes of difficulty:—

1. The trade effluents may be turned into the sewer at irregular intervals, so that the composition of the sewage as it arrives at the sewage works varies considerably throughout the day.
2. The trade effluents may contain large quantities of solids in suspension which tend to choke the purification plant.
3. The trade effluents may be very acid or very alkaline, or otherwise chemically injurious.

The general opinion of these witnes es, however, is that it is practicable, in the great majority of cases, to purify mixtures of sewage and trade effluents if the manufacturers adopt reasonable means for removing the solids, equalising the discharge, and, when necessary, neutralising the trade effluent.

Moreover, there is some evidence to indicate that even if the manufacturers do not adopt such means the purification of the mixture of sewage and trade effluents is still practicable, though the difficulties and cost are much greater.

But the evidence clearly shows that wherever practicable the manu-

facturer should adopt means for removing the bulk of the solids in suspension from his effluent, for neutralising it, and for delivering it into the sewer in a fairly uniform manner. And further, it would seem probable that in some cases the cost to the manufacturer of adopting these preliminary measures would be less than the additional cost which would be thrown on the local authority if the measures were not adopted. Indeed, there is evidence to show that occasionally the removal of the solids has been a source of profit to the manufacturer.

We have examined a large number of effluents from works where sewage containing trade refuse is being treated, and our results fully support the view that it is practicable in the great majority of cases to purify mixtures of sewage and trade effluents if the manufacturers adopt reasonable preliminary measures.

Separate Purification of Trade Effluents by Manufacturer.

18. We have not yet examined in detail the methods available for the purification of trade effluents, but from an inspection of some manufactories where considerable sums have been expended on purification plant which is inefficient, and also from the evidence, we are satisfied that in some cases at least the purification of the trade effluent by itself would be very difficult to accomplish.

Moreover, the evidence shows that the separate purification of trade effluents is generally more difficult and more costly than their purification when mixed with the ordinary sewage of the locality.

And it has been proved by the evidence and by our own inspection of manufactories that there are many cases, especially in towns, where the manufacturer has not sufficient space on which to erect purification works.

20. The position therefore is as follows :—

Purification of trade effluents by the local authority is in the great majority of cases practicable; purification by the manufacturer is in some cases difficult, if not impracticable; while purification by the manufacturer would generally be more costly than purification by the local authority. It also appears that the local authorities as well as the manufacturers are of opinion that there should be laid on the local authority a distinct obligation to receive trade effluents.

21. Further advantages which would follow from such a change in the law would be that the average standard of purification which would be reached throughout the country would be higher than if each manufacturer separately attempted to purify his own trade effluent, and also that the work of preventing the pollution of rivers

would be greatly assisted in that the number of purification works to be kept under observation would be diminished.

ALTERATION OF LAW.

22. We are therefore of opinion that the law should be altered so as to make it the duty of the local authority to provide such sewers as are necessary to carry trade effluents as well as domestic sewage, and that the manufacturer should be given the right, subject to the observance of certain safeguards, to discharge trade effluents into the sewers of the local authority if he wishes to do so.

We do not think it possible to provide by direct enactment what these safeguards should be. In each district it would probably be desirable that the local authority should frame regulations which should be subject to confirmation by a central authority. In most cases, however, these regulations could provide definite standards for the different manufacturers as regards preliminary treatment, and it appears from the evidence that manufacturers would much prefer to have standards to work to.

Power to vary the standards or to dispense with them altogether in special cases would be necessary.

23. Although the duty of receiving trade effluents should, we think, be imposed on the local authority, cases may arise in which they should be wholly or partially relieved of it.

For example, we find that in some instances the effluent discharged from the manufactory is of a composite character, the greater part of which might with advantage be easily dealt with by the manufacturer if it were kept separate. In such cases we think the manufacturer would generally be willing to adopt this course, but provision is necessary for those cases in which the local authority and manufacturer could not agree.

Further, although we have received no conclusive evidence to show that there are trade effluents which could not be purified by the local authority, we do not deny the possibility of such cases arising.

And it is possible that in some cases, as, for example, of a large manufactory being newly established in a small district, it might be necessary to relieve the authority of the obligation to treat the trade effluent or to enable them to exact some special contribution from the manufacturer not only for the cost of treatment, but also towards capital expenditure.

24. It is obvious therefore that some tribunal will be required for settling differences between the local authority and the manufacturer, and for relieving the local authority in exceptional cases either wholly

or partially of their obligation to provide sewers and disposal works of sufficient capacity for trade effluents as well as ordinary sewage.

We shall explain in a later section the plan which we think should be adopted.

Riparian Rights.

25. In many cases a part or the whole of the water which the manufacturer uses in his business is obtained from a stream, and must therefore be returned to the stream.

We do not propose that the manufacturer should by statute be relieved of this liability. If he is able to relieve himself from the obligation by obtaining the necessary consents from other riparian owners or by providing compensation water, then he might discharge his effluent into the sewer, but the responsibility must rest entirely on the manufacturer: the local authority should be expressly exempted from any liability for the infringement of riparian rights by the discharge into the sewer of water obtained from a stream.

Special Charge on Manufacturer.

26. We have taken a considerable amount of evidence on the question whether the manufacturer who discharges his trade effluent into the sewer should be required to pay something beyond his ordinary rates, and, as might be expected, the views expressed are divergent.

It appears that in some few cases manufacturers have by agreement with the local authority purchased the right to discharge crude trade effluents into the sewer.

27. The chief argument which has been used against a special charge being made is that a manufacturer who is heavily rated in respect of his premises is therefore entitled to the free use of the sewer.

This argument raises a general question of rating into which we do not propose to enter, but we may observe that other manufacturers producing little or no trade effluent are rated equally, and that, speaking generally, the amount of the trade effluent is not proportional to the rateable value of the premises.

29. Having regard to these considerations, we are of opinion that generally no special charge should be made on the manufacturer in those cases in which the regulations as to preliminary treatment are complied with.

As we have already stated, it is desirable that wherever practicable, some preliminary treatment should be carried out by the manufacturer.

But where the manufacturer is unable to comply with these regulations we consider that the local authority should be empowered to make a special charge.

Power should also be granted to make a special charge, even when preliminary treatment is adopted, where there are exceptional circumstances as regards volume, quality or otherwise.

30. We should leave the actual amount of the charges to be fixed by agreement between the manufacturer and the local authority.

In default of agreement the amount should be settled by a superior authority in the manner hereinafter explained.

31. In those cases in which a manufacturer is precluded from discharging his effluent into the sewer by reason of the fact that the water which he uses is obtained from a stream, and must therefore be returned to the stream, the duty of purification will still rest with him.

But we do not consider that this will be a serious grievance, as he obtains his water without charge, and this advantage may be set against the cost of purification.

Moreover it would be open to him to acquire the right to use the sewer by getting his water from some other source or by obtaining the necessary consents of riparian owners below him on the stream.

II. THE NEED OF SETTING UP A CENTRAL AUTHORITY.

The Settlement of Differences between Local Authorities and Manufacturers.

40. In an earlier section of this Report we have referred to the necessity of providing machinery for the settlement of differences between local authorities and manufacturers.

The chief questions upon which differences may arise are the following:—

1. The refusal of a local authority to allow a particular trade effluent to enter their sewers.
2. The refusal of a local authority to construct or enlarge sewers for the purpose of a particular manufactory.
3. The question of varying general regulations as to preliminary treatment by the manufacturer.
4. The amount of the special charge to be imposed on the manufacturer.
5. The removal of sludge.

Central Department Essential.

44. In our opinion a properly equipped central authority is essential, and we unhesitatingly recommend the creation of such an authority.

In the interests of river purification as well as of the trade of the country we consider it is of the highest importance that the changes

in the law which we have recommended should be made. But these changes would not in our opinion be of much use apart from the creation of a central authority for the determination of differences between the local authority and the manufacturer.

If the settlement of these differences be left to the ordinary Courts, differential treatment of manufacturers, with all the objections to it, will be certain to continue.

45. The central authority should have the following permanent chief officers:—

1. An administrative head.
2. A bacteriologist having special knowledge of the bacteriology of sewage, trade effluents and water supply.
3. A chemist having special knowledge of the chemistry of sewage, trade effluents and water supply.
4. An engineer having a special knowledge of geology and water supply.

It should also be provided with a laboratory.

46. The officers of the central authority must be clothed with the necessary powers to conduct inquiries, to call witnesses, to enter premises to take samples of the trade effluent, and generally to do such acts as are necessary for the proper performance of their duties.

47. At any inquiries which may be held neither counsel nor expert witnesses should be heard except with the special permission of the central authority.

48. The work of the central authority will be so intimately connected with the work of the Local Government Board that it will be desirable to make it a new department under the Local Government Board rather than an entirely separate department.

The Pollution of Rivers and the Protection of Sources of Water Supply.

60. At an early stage of our investigation we were struck by the fact that in many parts of England the pollution of rivers goes on unchecked, notwithstanding the fact that the Rivers Pollution Prevention Act has been on the Statute Book for over a quarter of a century, and in our Interim Report we deemed it necessary to state that the protection of our rivers is a matter of such grave concern as to demand the creation of a Supreme Rivers Authority.

General Position of our Inquiry.

77. In conclusion, we think it may be desirable briefly to explain the position of our investigations.

78. At the commencement of our inquiry we devoted considerable attention to general questions relating to the chemical and bacteriological analysis of sewage and sewage effluents.

The methods of bacteriological analysis which we have adopted are explained in a paper by Dr. Houston, which we presented with our Second Report.

A paper is now in preparation by Dr. McGowan in regard to chemical analysis, which will contain a detailed account of the work which has been done under our direction, with a view of settling the value of different methods of analysing sewage effluents.

79. We have completed a systematic investigation of the land treatment of sewage on farms of different kinds of soil.

This investigation has extended over a period of two years, and has embraced the bacteriological, chemical and engineering aspects of this method of disposing of sewage.

80. We are now making a similar investigation of artificial processes of various kinds at about thirty distinct places. This investigation will, we hope, be completed in about a year.

In addition certain authorities are, in conjunction with us, making similar systematic observations in regard to a number of artificial processes.

When these results have been collected, we shall endeavour, in compliance with the instructions contained in the second part of our Terms of Reference, to report on the different methods of treating sewage in the same and in dissimilar sets of circumstances.

81. In the meantime, we are taking evidence as to the discharge of sewage, sewage effluents, and manufacturing effluents into tidal waters. The importance of this subject as regards the contamination of shellfish has recently come into prominence. It is indeed a matter of great importance from the point of view both of public health and the fishing industries.

82. We are also continuing the investigations which we referred to in our Interim Report, for the purpose of ascertaining whether it is practicable to destroy those micro-organisms which are common to sewage effluents, and which may be dangerous, if the effluent flows into a river from which water for drinking is obtained, and we are generally considering what measures may be desirable to lessen dangers so arising.

83. Subsequently we propose to consider the methods available for the satisfactory disposal of manufacturing effluents when not mixed with ordinary sewage.

APPENDIX I.

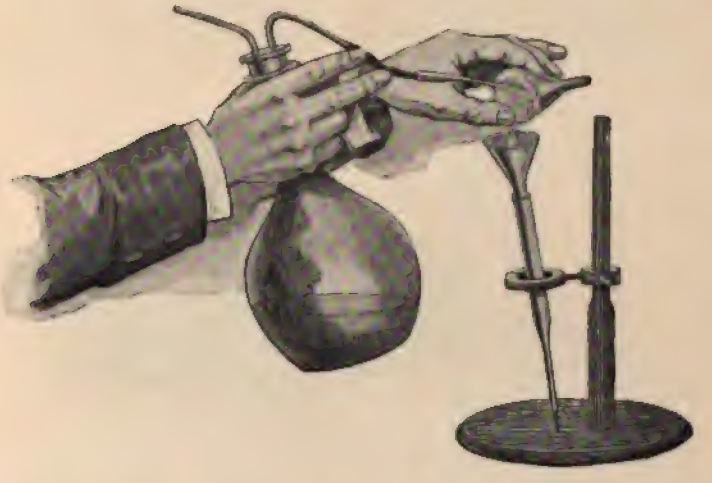
EXAMINATION FOR MATTERS IN SUSPENSION.

THE apparatus required for estimating the quantity of matters held in suspension may be very much simplified by adopting a method which I have recently described, viz., the micro-filter method. This does not give the results in terms of grains per gallon, but in that of volume instead. This difference, however, is not a matter of practical importance, as all that is required is the fact that a particular sample contains a larger or smaller quantity of solid particles. A comparison of actual determinations by the micro-filter and the gravimetric process will be found on page 304, Table LXXV. If the actual weight is required the water to be tested should be filtered through a filter-paper, the weight of which has previously been ascertained after drying at 212 deg. Fahr. for an hour or more until the weight is constant, and then weighed again with the suspended matters which have been collected on it, after a second drying in the same way, when the increase in weight found will indicate the weight of the matters originally in the sample—a simple calculation indicating the quantity in terms of grains per gallon—thus, if 700 c.c. of water are filtered, each 0·010 gramme will indicate 1 grain per gallon. Care must be taken to ascertain the increase in the weight of the dried filter-paper by the absorption of solid matters dissolved in the water, which would otherwise be counted as due to suspended matters.

The details of the micro-filter process are as follows: The neck of the bottle containing the sample is first carefully cleansed to remove extraneous dust. If a drinking water, or one containing but minute quantities of suspended matter, one litre of the water, or proportionately less when the quantity of sediment is evidently large, is decanted into a clean litre flask having a narrow neck, such as those used in the well-known Bischoff's bird fountain, which I have found to be specially suited for the purpose. A clean filter-paper, about 3 in. in diameter, is placed in position in a glass funnel resting in the neck of a flask or bottle of at least a litre in capacity. Then the flask containing the water is inverted, so that its mouth is just below the level of the top of the filter-paper. The water will at once fill the

PRELIMINARY FILTRATION OF THE WATER THROUGH HARD FILTER-PAPER.

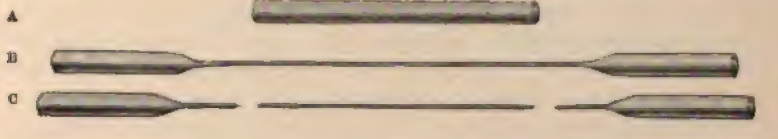
filter-paper, and so close the mouth of the flask, thus acting in the ordinary way of the bird fountain, feeding the supply in the filter until the whole of the water has passed through. During this operation, which will take an hour for a good clean drinking water, great care must be taken to exclude dust by placing a perforated card, through which the neck of the inverted flask passes, over the funnel. When the water is thus filtered, the deposit obtained on the paper, to which



MICRO-FILTER.
Washing the deposit from filter-paper into micro-filter.

it lightly adheres, is washed by a fine jet of water from a laboratory wash-bottle into the micro-filter.

The micro-filter is prepared by selecting a length of glass combus-

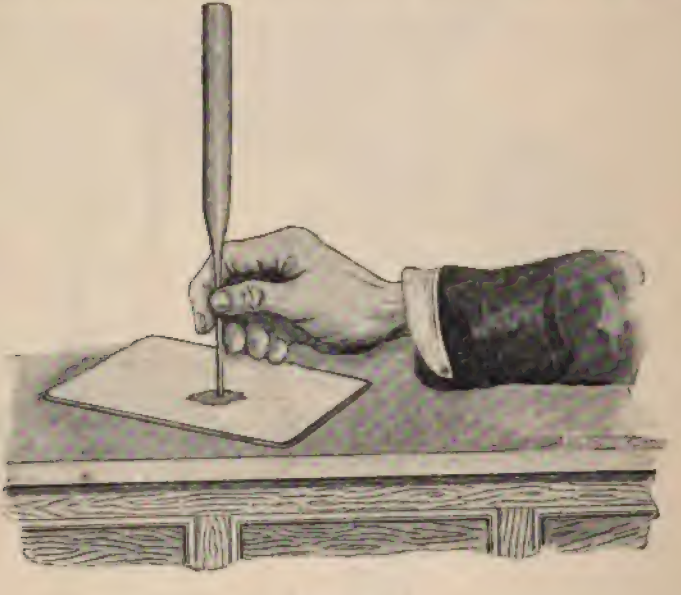


CONSTRUCTION OF MICRO-FILTER.

A Plain combustion tube.
B Same drawn out.
C Divided so as to form two micro-filters.

tion tubing, from 8 in. to 10 in. in length, which after thorough cleansing by drawing a wet plug of cotton wool through it, is heated to redness over a blowpipe flame in the middle, and pulled out when soft to a capillary tube.

The diameter in the thinnest part should be something less than two millimetres. It is then cut with a sharp file at the two points at which the capillary tube is exactly two millimetres in diameter, and neatly broken. By this means two micro-filter tubes will be prepared.

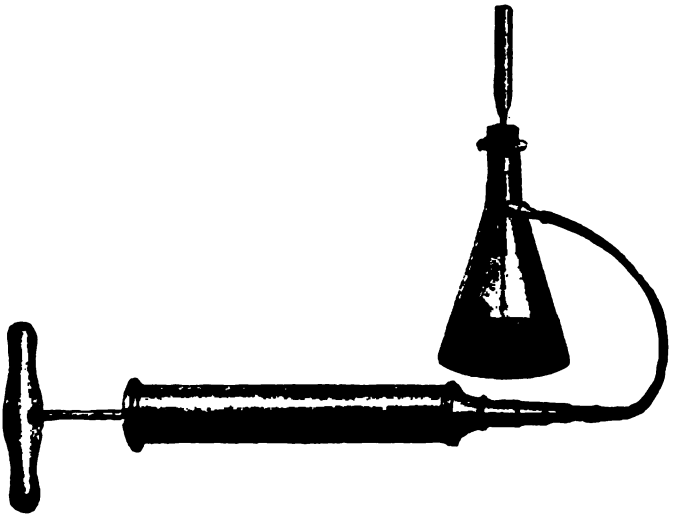


MICRO-FILTER.
Forming the porous filter-plug.

They are then converted into filters by charging the small ends with a suitable porous diaphragm prepared by mixing about one part of powdered air-dried clay with three parts of Kieselguhr. This mixture is moistened and worked up by rolling between the palms of the hands into a smooth putty, which must be spread out to a depth of two millimetres on a clean plate of glass or glazed earthenware. The filter tube being held upright in the manner of a pencil, with the small end downwards, is pressed steadily on to the mass of clay and Kieselguhr, and then worked round to free the enclosed portion on the tube from the surrounding mass. This separation will be facilitated by moisten-

ing the glass tube with water just before pressing it on the clay, &c. By this method the capillary tube will be neatly charged with a plug of the mixture. This is next dried in the flame of a lamp and gradually heated to redness, when the burnt clay will set hard and keep the Kieselguhr in position, and so form a porous diaphragm admirably suited for the purpose of a minute filter. If a little air is sucked through the tube while the plug is red-hot, the organic matter always present with the Kieselguhr will be completely destroyed and the filter made more porous.

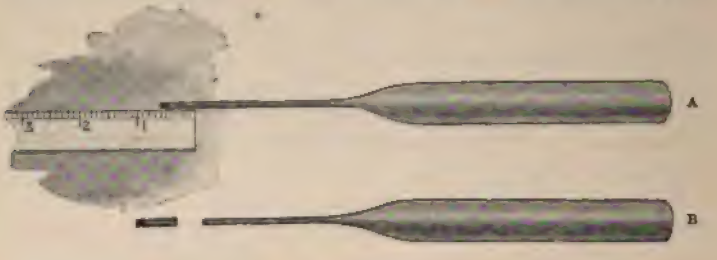
As the fine sediment from the water will often choke the pores of this small plug, the filtration may be conveniently accelerated by



MICRO-FILTER SUBJECTED TO VACUUM.

using it in connection with any convenient hand-suction pump such as that depicted above. When only about half-an-inch of water remains in the micro-filter, the depth of deposit on the filter-plug is measured, and the results expressed in terms of *millimetres of deposit in a two-millimetre diameter tube per litre of water.* Thus, a numerical factor is obtained which expresses the actual volume of suspended matter present in a water. Of course, in the case of dirty water, effluent, or sewage, when the deposit from a litre would be too great to be contained in that part of the micro-filter tube having a diameter of about two millimetres, half or a quarter of that quantity

may be taken, or even less, say, 5 or 10 c.c., when it may be placed in the filter-tube direct without the preliminary filtration through paper,



MICRO-FILTER.

A Measuring depth of deposit.
B End of filter-tube containing deposit cut off.

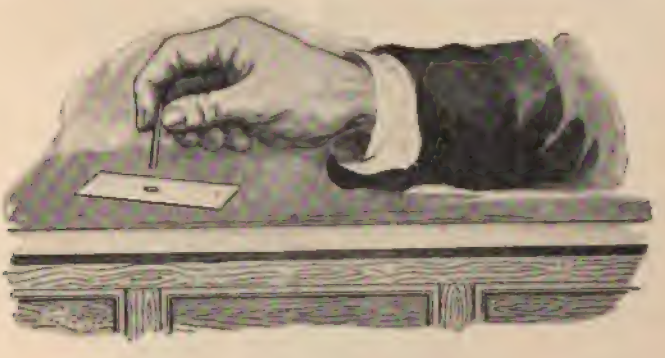
and the depth of deposit actually found should be multiplied accordingly, so that the result, in all cases, even with the most foul water where only a few c.c.'s can be used, may be expressed in the same terms of "millimetres per litre." In some cases it is difficult to induce all the water to pass the plug, but where only the depth of deposit is required,

MICRO-FILTER.

A Loosening deposit with wire from filter-plug.
B Deposit collected at open end, and plug cut off.

the solid matters may be made to collect rapidly at the end of the fine tube by holding the stout end in the fingers, and with a long sharp sweep at arm's length, inducing them to fall to the thin end by centrifugal action.

If a microscopical examination is to be made of the suspended matters, a scratch with a file is made on the capillary tube about half an inch from the plug and the piece broken off. By means of a thin platinum wire inserted in the bore the suspended matters collected may be detached from the plug and held in suspension in the small quantity of water present. Another scratch is then made on the glass tube close to the plug which is broken off, and the few drops of water remaining with the suspended matter shaken out on to the usual glass slip.



MICRO-FILTER.

Shaking the drop of water with deposit on to microscope slide.

A modification of this method was employed by Professor Boyce and Doctors Grünbaum, MacConkey, and H. Gill in their "Investigation of the River Severn in the Shrewsbury District" (p. 95, Second Report of the Royal Commission on Methods of Treating and Disposing of Sewage, 1902). Their method was to collect the deposit from 600 c.c. water by centrifuging and then to transfer the deposit so obtained to smaller tubes, comparable to those above described but with the small end sealed, and then to centrifuge these, when the solid matters collected in the small end and the amount was read off.

APPENDIX II.

DISSOLVED OXYGEN.

In order to facilitate the extraction of the dissolved gases from the water, I devised a mercury pump by which the operation is both simplified and expedited.

The pump is a modification of Macleod's apparatus, and is shown in the accompanying woodcut.

MERCURY EXHAUST PUMP FOR ESTIMATING DISSOLVED GASES IN WATER.

It consists of an inlet tube, through which water can be drawn by lowering the mercury vessel; a measuring tube, surrounded by a cold-water jacket; a boiling bulb, surrounded by a warm-water jacket; a mercury reservoir, by means of which the whole apparatus can be filled with mercury; a delivery tube; and a two-way tap connecting the measuring vessel with inlet or outlet at will. To use it, the apparatus is first filled with mercury by raising the reservoir, the tap being open first to the outlet and then to the inlet; the inlet tube is then inserted into the water to be examined, and the reservoir slowly lowered until the required amount of water is drawn into the graduated vessel. The tap is then shut off and the mercury lowered so as to draw the water into the lower bulb, where the gases contained in the water are boiled out by surrounding the bulb with warm water over 120° F., the upper bulb being kept cold to condense the water vapour. The tap being open towards the outlet, the mercury reservoir is raised and the extracted gases driven over into a receiving tube. This operation is repeated twice, and the collected gases measured and analysed in any convenient apparatus.

By means of this apparatus the quantity of dissolved oxygen contained in a sample of water can be determined in from twenty to thirty minutes, and the result, of course, is not vitiated by the presence of organic matter, as is the case with the other two processes.

THRESH'S METHOD.

The process of Dr. J. C. Thresh is based on the fact that whereas, in absence of oxygen, nitrous acid and hydrogen iodide interact to form iodine, water and nitric oxide; in presence of oxygen the nitric oxide becomes re-oxidised, and, serving as a carrier of the oxygen, an amount of iodine equivalent to the oxygen present is liberated in addition to that resulting from the initial action of the nitrous acid; hence, deducting the amount liberated by the nitrous acid and by the oxygen dissolved in the solutions used from the total amount, the difference will be that corresponding to the oxygen dissolved in the water examined.

The apparatus is shown on p. 354.

The solutions used are:—(1.) A solution containing 0·5 grm. sodium nitrite, and 20 grms. potassium iodide in 100 c.c.; (2.) a solution of 7·75 grms. sodium thiosulphate in 1 litre, 1 c.c. of which corresponds to 0·25 mgrm. of oxygen; (3.) a clear solution of starch; and (4.) diluted pure sulphuric acid (1 : 3).

The apparatus required is as follows:—A wide-mouth, white glass bottle of about 500 c.c. capacity, provided with a caoutchouc stopper, through which four holes are bored. Through one passes the neck of

a cylindrical "separator" funnel of known capacity, and through the second a tube drawn out to a fine point, which is connected by a short length of caoutchouc tubing with the thiosulphate burette. Inlet and exit tubes for coal-gas are passed through the third and fourth holes, the exit tube having attached to it a sufficient length of caoutchouc tubing to permit of connection being established between the bottle and the separator when the stopper of the latter is withdrawn.

THRESH APPARATUS FOR ESTIMATING THE DISSOLVED OXYGEN IN WATER.

The separator, the capacity of which is known, is filled with the water to be examined, and 1 c.c. of the nitrite iodide solution and 1 c.c. of the acid solution, are added. If the pipette be held vertically, with its end just below the surface of the water, the solutions flow in a sharply-defined column to the lower part of the separator, so that an infinitesimally small quantity (if any) is

lost in the water which overflows when the stopper is inserted. The admixture of the liquids having been effected by inverting the apparatus several times, a sharp current of coal-gas is passed into the bottle to displace the air, the escaping gas being allowed to burn at a jet attached to the exit tube. Fifteen minutes after adding the solutions to the water the flame is extinguished, a cork is attached in place of the jet, and is inserted in place of the stopper of the separator, and the water is then allowed to flow into the bottle; the exit tube having been disconnected from the funnel and the gas set fire to, thiosulphate is run in until the colour of the iodine is nearly destroyed; about 1 c.c. of starch solution is then added through the separator, and the titration completed. The effect of the nitrite, dilute acid and starch solutions is readily determined by removing the separator and adding 5 c.c. of each in succession, and then titrating; the effect of the oxygen in the thiosulphate may be allowed for on the assumption that as much oxygen is dissolved in it as distilled water would contain at the same temperature. It appears that there is no advantage in passing the coal-gas through alkaline pyrogallol.—*Journal Soc. of Chem. Ind.*, Mar. 31, 1890, p. 327.

SCHUTZENBERGER'S PROCESS.

Arranged and modified by Dr. Dupré and Mr. W. J. Dibdin.

The apparatus at first sight appears more complicated than it really is. The essential parts consist of two burettes with their dropping tubes passing through a stopper inserted in the centre neck of a Wolff's bottle, through which a constant current of hydrogen is kept passing for the purpose of excluding atmospheric air. Through the stopper in the right hand neck the tubular of a tap funnel or separator is passed to the bottom of the bottle, for the purpose of introducing the water to be tested. This separator should hold about 250 c.c. A small bent glass tube passes just through the cork, and is connected by indiarubber tubing to a wash-bottle partially filled with water, which acts as a seal for the purpose of preventing the diffusion of the hydrogen from the Wolff's bottle. Through the left hand cork of the Wolff's bottle two glass tubes pass, one for the admission of hydrogen from the generating apparatus, stopping short above the surface of the liquid, and the other to the bottom of the bottle for the purpose of withdrawing the liquid from time to time, a length of indiarubber tubing, provided with a clip, being attached to it so as to convert it into a syphon. Through the same cork a second, but smaller, separator is passed for the purpose of introducing small quantities of fully aërated water, when it is necessary to neutralise any excess of the standard hyposulphite solution which may have been inadvertently run into the bottle.

The standard solution of hyposulphite is contained in a large bottle on a stand, and is run into the burette through the length of indiarubber tubing connecting it with the bottom of the burette, and terminating below the surface of the liquid in the bottle, a clip being provided for regulating and stopping the flow. To prevent the introduction of atmospheric oxygen into the bottle of standard solution the tube supplying the hydrogen to take the place of the removed solution dips through the cork of a small bottle containing an alkaline solution of pyrogallic acid; through this cork a second tube passes to the bottom of the bottle so that the gas is washed by the solution and deprived of its oxygen, if any. The second small bottle is provided as a catchpit to catch the alkaline solution in case of accident or expansion of the gas in the stock bottle. A screw clip is provided on the indiarubber connection between the stock bottle and the inlet tube for the purpose of preventing the gas, in case of expansion, from driving the pyrogallic acid solution out of the absorption bottle, and thus leaving a free passage for the diffusion of oxygen into the stock bottle, which would weaken the hyposulphite solution. A similar arrangement of bottles, or rather tubes, is provided at the top of the burette for absorbing atmospheric oxygen from the gas before it enters the burette when the standard solution is run out.

The second burette is for the solution of indigo which is to be used as an indicator, only sufficient being run into the Wolff's bottle to give a distinct colour.

Before commencing a titration all the hyposulphite solution in the burette and the tubes is to be carefully run off, and the burette refilled with fresh solution from the stock bottle. The hydrogen is sent through the apparatus to remove all atmospheric oxygen, which is best kept out when the apparatus is not in use, by stopping the current with a tap or plug inserted in the sealing bottle connected to the right hand cork of the Wolff's bottle, so that a pressure of hydrogen is always maintained; the tap of the generating apparatus being left open.

To make an experiment, syphon off the liquid in the bottle and run in a small quantity of clear and fully aërated water from the separator, then add just sufficient indigo solution from its burette to give a decided blue tint, and add drop by drop the hyposulphite solution until the blue colour is just discharged, now add an excess of hyposulphite solution; then immediately run in the water to be tested from the separator, which has been previously filled by means of a syphon to prevent, as far as possible, the water from coming in contact with the air. As soon as the blue colour of the indigo returns add more hyposulphite. The object of this method of procedure is to prevent the oxygen of the water being displaced by the hydrogen,

thus interfering with the accuracy of the determination. If the hyposulphite is kept in slight excess until just before the end of the reaction no free oxygen will be present, as it is instantly absorbed. As soon as the separator is empty shut off the cock, and add the hyposulphite solution, drop by drop, until the blue colour is just discharged. The quantity of hyposulphite solution used is to be noticed. The strength of the hyposulphite solution is readily ascertained by making a similar experiment with fully aërated water, the mean of two determinations being taken in all cases. The use of the table is obvious. Note the temperature of the fully aërated water used to standardise the solution, and also that of the water under examination, then the necessary calculations can be readily made. As the same quantity of water is used in all cases no correction for quantity is needed, as the results so far are strictly comparable. The results should be stated in percentages of the quantity of oxygen which the water is *capable of absorbing at its particular temperature*, as well as in actual cubic inches.

Table LXXIX.

Showing the Quantity of Oxygen Dissolved by Water at various Temperatures. Corrected to 0° C. at 760 m.m. pressure.

Temperature Fahrenheit.	Temperature Centigrade.	Cubic Inches of Oxygen per Gallon.
41°	5·00	2·40
42	5·55	2·37
43	6·11	2·34
44	6·66	2·31
45	7·22	2·28
46	7·77	2·26
47	8·33	2·23
48	8·89	2·19
49	9·44	2·17
50	10·00	2·15
51	10·55	2·12
52	11·11	2·09
53	11·66	2·07
54	12·22	2·04
55	12·77	2·02
56	13·33	2·00
57	13·89	1·97
58	14·44	1·95
59	15·00	1·93
60	15·55	1·90
61	16·11	1·88
62	16·66	1·86
63	17 22	1·83
64	17·77	1·81
65	18·33	1·79
66	18·89	1·77
67	19·44	1·75
68	20·00	1·73
69	20·55	1·72
70	21·11	1·70

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LONDON:

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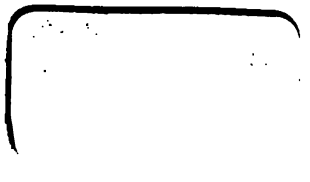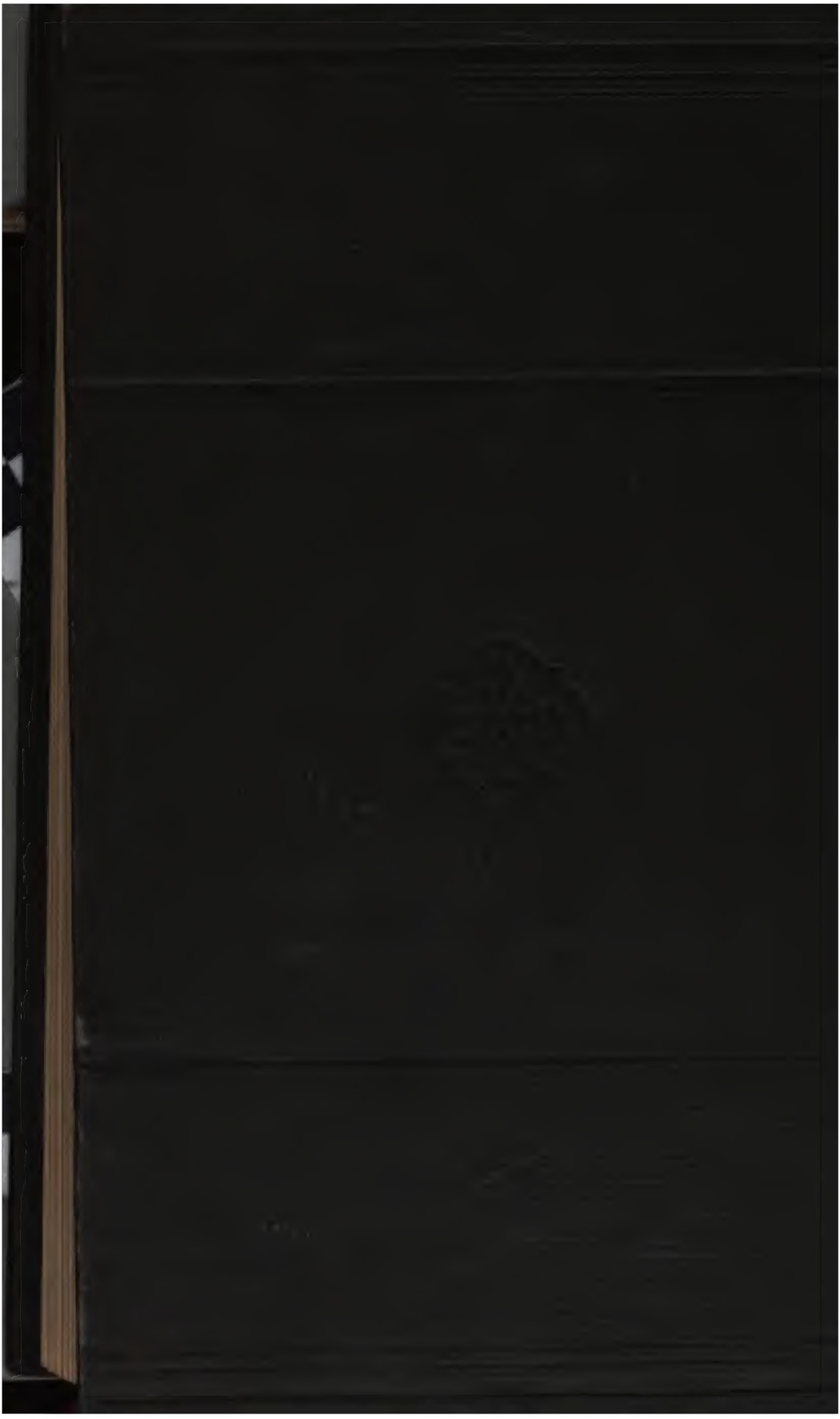
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